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Transboundary Fire and Haze Games: Local Capture and Common Agency

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Abstract

We study how transboundary, intergovernmental fire and haze negotiations interact with local, subnational government collusion and capture in a decentralized country. The local government collusion and capture problem is modelled as a competing principals and common agency problem that interacts with the central government's transboundary game of chicken. The results show that the central government can persuade farmers and prevent burning when the incremental benefits from slashing and burning are lower, the total direct and indirect costs and damages of fire and haze are higher and the required enforcement and abatement costs are not too high. Neighbouring governments can help mitigate the central government's budget constraint and punish violating multinational companies. We develop a multitask multiprincipal framework to expand our solution set to include partial burning outcomes and negative compensations. The results inform on a set of policy strategies to these complex transboundary fire and haze negotiation and local capture problems.

Keywords: forest and peatland fires, mechanical clearing, slash and burn, game of chicken, multitask, multiprincipal, common agency, collusion and capture

JEL classification: Q23, Q57

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1 Introduction

Man-made forest and land burnings continue to be pervasive across the larger islands in Indonesia, especially Sumatra, Kalimantan and Papua.[1] The so-called slash and burn practices are often more profitable for oil palm and timber plantation companies than mechanical means of clearing lands, and potentially more lucrative for individual and small groups of farmers. This cost advantage of burning over zero burning is particularly pronounced in heavy forests (up to 70%) and peat swamps (more than 350%) (Gouyon and Simorangkir, 2002). The resulting transboundary haze pollution, exacerbated by extreme weather events such as El Nino and draughts, has become a health and economic problem for Indonesia and its neighbouring ASEAN countries since the 1990s, when oil palm was identified by the government of Indonesia as one of the strategic sectors to help promote growth in exports. While forest and especially peatland fires result in direct damages to equipment and infrastructure and direct costs of health treatment and fire fighting, the indirect or secondary negative impact of fires and the resulting transboundary haze pollution is even higher. The latter include the costs of subsequent land reclamation and foregone production revenues (during the replanting period), environmental damages and biodiversity losses as well as opportunity losses to local, regional and cross-border trade, industry and tourism activities (Glauber and Gunawan, 2016). Approximately 100,000 fires across 2.6 million hectares of Indonesian lands burned between June and October 2015, estimated to result in total direct and indirect damages and costs of over USD16 billion to the country (Glauber and Gunawan, 2016).

Despite repeated pressures and multiple treaties with neighbouring ASEAN governments and multilateral institutions, limited progress has been achieved in the attempts to prevent and mitigate forest fires and the resulting haze pollution as well as in stricter enforcement of zero burning policies for medium- and large-size plantation companies and farmer groups[2]. Neighbouring governments such as Malaysia and Singapore who have tried to engage and help the central and local governments in Indonesia in their enforcement and abatement programs have been thwarted by nationalistic and local business interests. While continuing to engage the Indonesian government,

[1] See for examaple Purnomo et al. (2017), Edwards and Heiduk (2015), Ekadinata et al. (2013), Quah and Tan (2018) and multiple studies and publications by Center for International Forestry Research (CIFOR) in West Java, Indonesia (website: www.cifor.org). The Republic of Indonesia's Law No. 32 (2009) on the Protection and Management of Environment and Government Regulation No. 4 (2001) on Management of Environmental Degradation and/or Pollution prohibit the use of burning for land clearing. The government does, however, allow slash and burn practices for financially constrained individual and small groups of farmers clearing less than 2 hectares per family or 20 hectares in aggregate.

[2] See, among others, Glauber and Gunawan (2016), Nguitragool (2011), Purnomo and Shantiko (2015, 2017), Tan (2015).

some of them have identified possible policy leverage against a subset of larger and internationally operating plantation companies. Singapore, in particular, has ratified its 2014 Transboundary Pollution Act (Tan, 2015). This Act is not expected to be able to force the Indonesian government to comply and fulfill its responsibilities under international laws, which include due diligence and information sharing responsibilities. However, the Act does give Singaporean courts the power to prosecute Singapore-domiciled or Singapore Stock Exchange-listed plantation companies. Nevertheless, difficulties in matching data on burning concession areas, verifying land rights and maintaining control over burning practices taking place in multiple areas across Indonesia may still pose challenges to the Singaporean courts (Tan, 2015).

Rusli (2018) models and observes that a central Indonesian government that takes a holistic perspective and considers in its welfare objective all direct and indirect costs of fire and haze finds itself in a repeated game of chicken with its neighbours. The classic two-party stage game of the game of chicken is known to have three Nash equilibria. Applied to the fire and haze game either one party invests in enforcement and abatement unilaterally, or the other does so on its own, or both play mixed-strategies between investing or not investing in enforcement and abatement. However, in practice, the central government's efforts are impeded by a strong local collusion of local bureaucrats, business elites and plantation companies (Purnomo et al. 2015, 2017).[3] These local collusion groups weigh the extra profits from slash and burn practices against local, direct costs of fire and haze. They perceive significantly lower damages and costs from fire and haze than the nation-wide direct and indirect longer-term costs to the industry and the environment. They may also have the power and rents to incentivize farmers and residents to engage in illegal slash and burn land clearing practices, even when it means undermining or capturing the central government enforcement and abatement efforts. At the same time, central government negotiators that are primarily led by the Ministry of the Environment lack the authority and face ongoing decentralization forces and resistance from the Indonesian legislature (Nguitragool, 2011). While the Ministry wields decision making authority over land and forest policy at the central bureaucratic level, it does not possess the power to enforce domestic laws on local land and forest fires.

[3] Purnomo et al. (2015, 2017) study the economic, social networks and political causes of forest and land fires by collecting post fire site data and conducting focus group discussions with key stakeholders. The benefits and profits from slash and burn for land clearing are distributed amongst multiple potential beneficiaries ranging from local business elites, plantation companies, local bureaucrats including provincial governors, district heads, local forestry officials and the local legislature, to farmer and individual land-owners engaged in slashing, cutting, burning activities. Disentangling the cost-and-benefit calculation and in turn the incentives of each key player in the local political and business value chain, they find that local business elites gain the most from capturing local bureaucrats and organizing local farmers and residents to engage in slashing and burning activities.

By contrast, Edwards et al. (2020a) conducted randomized controlled trials (RCT) experiments in remote villages in Kalimantan. They study the effects of educational programs, payments for ecosystem services and conditional cash transfers on 90,000 local households, specifically on residents' and farmers' behaviour vis-a-vis slashing and burning. The disappointing results were attributed to the short time frame, small amounts paid-out, collective action failure and focus on extensive margins. Furthermore, Edwards et al. (2020b) used geospatial data on forest fires to identify the underlying causes of forest fires at the district and village levels. They find that villages are more likely to experience forest burnings the more remote their location, the less economically developed they are and their respective history of slashing and burning. Interestingly, economic growth and development exacerbate burn practices, which suggest reverse-causality and an endogenous relationship between economic development and slashing and burning practices.

In this paper we study the question of how the central government can incentivize local farmers and residents to put in efforts and engage in legal zero burning mechanical land clearing or to take-on other means of employment. The central government must outbid the local collusion group's attempt to compensate and motivate farmers and residents to engage in slashing and burning of the forests and peatlands targeted by the local collusion group. We develop a model of competing principals to examine the incentive and budget constraints of the central government versus a local collusion group. In particular, we identify the maximum incomes and compensations the two principals are able to offer to local farmers and residents. We find that the central government can persuade farmers and prevent burning when the incremental benefits from slashing and burning are lower, the total direct and indirect costs and damages of fire and haze are higher and the required enforcement and abatement costs are not too high. Neighbouring governments can help mitigate the central government's budget constraint and deter or punish violating multinational companies. However, attempts by the central government to solve the local capture problem will incentivize the neighbouring government to either free-ride or, only if necessary and unavoidable, to aid the central government.

Furthermore, we derive a dual-task dual-principal model based on Dixit's (1996) multitask common agency model to expand our solution set. Here the central government faces moral hazard issues with regard to the farmers' actions and thus introduces a combination of positive incentives and negative punishments to prevent slashing and burning in at least part of the forest and peatlands. Such partial outcomes will be better than losing all the relevant forests and lands to slashing and burning organized by the local collusion group.

Our results inform on several policy strategies. The optimal solution is for the central govern-

ment and its neighbours to jointly invest in enforcement and abatement and strictly punish violating companies. Farmers can be offered alternative employment and training as part of broader, more sustainable industrialization programs. Local bureaucrats and companies can be encouraged to engage in alternative welfare-enhancing infrastructure projects. Information campaigns and technological innovation can correct misconceptions and improve efficiency in abatement and mechanical land clearing. Concurrently, the central government should find ways to break the local collusion by compartmentalizing information, misaligning incentives and inducing competition amongst the members of the local collusion group.

Our contribution to the literature is threefold: First, in the specific context of Indonesia's fire and haze problem our analysis dissects the local common agency problem and offers policy strategies to the local government capture and farmers' incentive problems. We propose strategies to solve the persistent incentives for local business elites, bureaucrats, plantation and timber companies to collude and engage in slashing and burning, which Purnomo et al. (2015, 2017) observe. We also derive that sufficiently high compensation can persuade farmers to avoid slashing and burning (supporting Edwards et al. 2020a), while education and industrialization can help farmers benefit from other employment opportunities (Edwards et al., 2020b). Second, we shed light on how the local capture and common agency problem interacts with the game of chicken between the central government and its neighbours. This helps us expand on Rusli's (2018) solutions and his policy recommendations, which in turn help address the transboundary negotiation impediments characterized by Nguitragool (2011) and Tan (2015). Additionally, we offer a theoretical basis for future empirical tests to identify the main causes of slashing and burning, which will help expand on the results of Edwards et al. (2020a and 2020b). Third, past game theoretic studies focus on international environmental cooperations and agreements (e.g. Eyckmans and Finus, 2008, Finus, 2001, Chander and Tulkens, 2011) and on dynamic or differential games (Bertinelli et al., 2015, Calvo and Rubio, 2013). By contrast, we interact transboundary environmental bargaining with local capture and common agency problems. Our model setup can thus be applied to other transboundary bargaining situations involving a politically or fiscally decentralized country, where the central government faces interference from local, subnational-level interests. To our knowledge, this has not been explicitly studied.

Our competing principals model can be adapted to address repeat bargaining, adverse selection and moral hazard, monitoring and signalling. The dual-task dual-principal model can be expanded to include additional principals, accounting for possible fragmentation of the local collusion group, the participation of neighbouring governments and farmers' outside (e.g. industrial) employers.

Going forward we anticipate research interest in empirical studies on the impact of subnational-level socioeconomic and political drivers of forest fires and different land clearing methods, particularly in politically decentralized countries. We also expect continued interest in studying the political economy and roles of multilaterals, governmental and non-governmental organizations in forest and peatland fires and other environmental problems faced by budget-constrained central governments in decentralized developing countries.

Following this introduction and literature overview, we describe local capture and common agency problem facing the central government in section 2. We derive and discuss the transboundary fire and haze game and our local common agency models in Section 3. We also discuss how the local common agency problem affects the transboundary game solutions. Section 4 discusses our proposed policy solution strategies, while Section 5 summarizes and identifies areas for future research and policy evaluation.

2 Local Capture and Common Agency

Neighbouring governments suffering from the transboundary haze exert pressure and bargain, individually and collectively, with the Indonesian central government to force the latter to invest in strictly enforce zero burning, mechanical land clearing regulation and practices. However, in implementing the terms of the ASEAN Haze Treaty, the Indonesian central government faces problems around the environmental ministry's lack of authority, the increased autonomy of local district level governments and the delayed ratification of the Treaty by the legislature (Nguitragool, 2011).

A very important aspect of this Indonesia haze game framework concerns the incentives of the key players involved in the game. While a rational and benevolent central government in Indonesia may look at the aggregate nation-wide costs and benefits of fire and haze enforcement and abatement, the central government could face problems aligning the interests of national legislators, local governments and legislatives, business elites, farmers and residents. The key beneficiaries of slash and burn practices, which together enjoyed roughly USD3,077/hectare of benefits, include plantation companies (around 30% of total benefits), various groups of small and individual farmers and residents involved in slashing, cutting and burning (14%), village heads (3%) as well as, in particular, local group organizers which primarily comprise local business elites (more than 50% of the benefits) (Purnomo et al., 2015, 2017).

As can be inferred from the simplified scheme in Figure 1, each of these parties enjoy distinct benefits and are affected in different ways by the forest fires and haze pollution. Local farmers

and residents, in particular, are influenced by multiple principles, including not only the central government, but also business elites, plantation companies and bureaucrats. Business elites with close connections to local government and legislatives as well as local businesses and plantation companies typically spot profitable opportunities such as, in this context, slash and burn land clearing projects. They usually target the smaller local and national companies and farmer groups who will benefit most from the cost advantages of slash and burn while being less exposed to international reputational risks. These business elites may be able to capture and convince local bureaucrats to either look away or, in some instances, help hide and manipulate data about burning acreage, their ownership and origins. Local bureaucrats could be tempted to collude with the local business elites, and may seek the latter's help in convincing the local legislative members not to object to these potentially lucrative business dealings, and to convince their national-level party colleagues to resist onerous laws and regulations that may jeopardize such business activities.

It is noteworthy that from the perspective of local bureaucrats, more profitable business practices tend to generate higher income to the local economy, through tax receipts and economic spillovers like infrastructure etc.. On national and international levels, larger plantation or forestry companies may decide that to invest in or purchase burned lands may be too big of a reputational and business risk for them. Instead they may opt to assist the government in its enforcement and abatement efforts, and employ the farmers and residents to aid in their zero burning mechanical land clearing works.

Local farmers especially in less industrialized regions may not have tangible income alternatives other than working in plantation acreage, either independently or as employees or contract workers for such companies. Farmers have to choose between engaging in the often more lucrative slash and burn activities, and the compensation they might earn from working in other types of farming or for companies conducting legitimate land clearing activities. While individual farmers with acreages not exceeding 2 hectares per family and small groups of farmers with combined acreage of less than 20 hectares are by law permitted to engage in controlled forest burning, it is often local business elites that are proficient in coordinating individual and small farmer groups and bundling and on-selling such transactions to plantation companies that are willing to take the risk, in return for a share of the potentially higher profits.

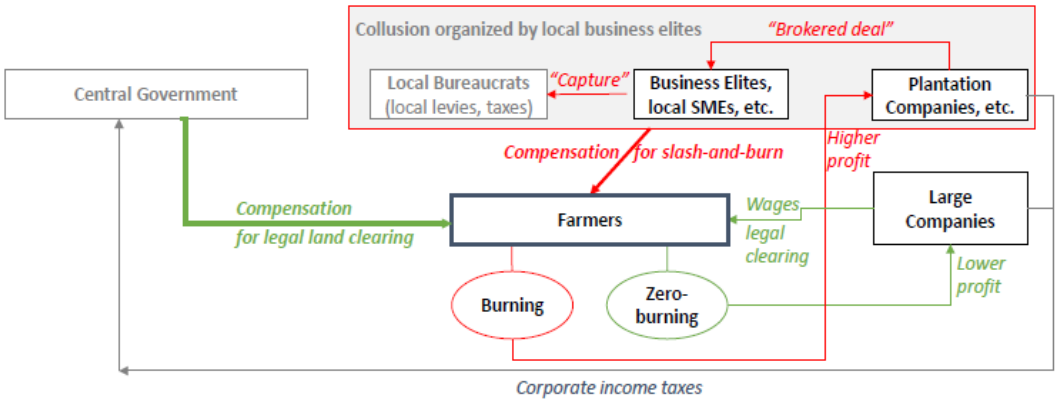

Figure 1: Local political-economy of land clearing

The transboundary negotiation process with neighbouring governments is therefore not led by the Indonesian central government as one coherent authority, but affected by multiple decision makers operating in a complex multiprincipal common agency environment. Each agent makes its own cost-benefit calculation. Combined with the possible myopia, bounded rationality and capture problems faced by the central government itself, the transboundary negotiations are also affected by local and regional challenges. Just like the purely utilitarian business elites, local bureaucrats and farmers are less likely to consider the broader, nation-wide indirect economic and environmental losses of fire and haze. At the same time, plantation companies, except for the larger national and international ones, tend to focus on their profit maximization objective, with lesser regard for reputational and long-term costs.

Only the central government and environmental ministry, often under pressure from foreign and neighbouring governments, multilateral and non-governmental organizations, may wish to consider all indirect damages and losses of fire and haze in their decision making and negotiations. However, the central government may still face information problems. In fact the central government and its environmental ministry face a complex set of adverse selection and moral hazard problem. First, they may not be able to identify exactly which farmers, companies and bureaucrats are involved in the illegal slash and burn activities, who may as a consequence try to impede investigations and the passing of preventive and remedial legislation (an adverse selection issue). Second, the central government may not observe the full extent of slash and burn practices and the exact areal sizes and locations of the forests and peatlands affected. The latter information may be hidden activities by farmers, endorsed by local bureaucrats as well as companies who may have been captured by the business elites (a moral hazard problem). These domestic institutional and

governance challenges as well as incentive incompatibility problems have significantly delayed the ratification of the ASEAN Haze Treaty. In turn, they have rendered the coordinated abatement enforcement efforts of Indonesia and its neighbours difficult and protracted.

3 Models

We start with the central versus neighbouring government transboundary haze and fire game. We then continue with the two local capture and common agency models. We also analyze how the transboundary game interacts with the local capture and common agency results. Throughout this analysis, unless specified otherwise, we assume that central government is benevolent and concerned about the overall well-being of the country's populace, economy and environment and prefer zero burning, while the local government officials in our scenarios are captured by local business interests and companies and prefer slash and burn.

3.1 Transboundary Fire and Haze Bargaining Model

Distilled down to its basic features, the transboundary negotiations and free-riding problem can be analyzed by way of a two-by-two game (Rusli, 2018). The game comprises two players, the Indonesian and the neighbouring government. Each of the two players choose between two policies, whether to invest in and implement enforcement and abatement policies to target zero burning, or not. In case of the status quo or not-invest policy, profitable slash and burn methods of land clearing continue unabated; with all the health, economic, environmental and societal costs - and benefits. We examine two main cases and discuss the possible variations to each.

Our first-best ("FB") case assumes that the Indonesian central government (the "Center") acts as a benevolent planner with complete information over all agents, public and private, and all benefits and costs across the country. The government is utilitarian and calculates aggregate welfare as the sum of the income tax revenues it receives from local and national companies, farmers and residents, plus their respective profits, wages and incomes.[4] In cases of forest and peatland fires, the government subtracts from the tax revenues, company profits and farmer incomes the

[4]Throughout this paper we use "forests" to represent forests and peatlands, "companies" to include domestic and international palm oil and timber plantation companies. Next, for convenience we shall denote "farmers" to include all local residents and "incomes" to capture the farmers' wages and other income sources. We shall also define local bureaucrats to include district- and village level executive officials and legislatives (Gouyon and Simorangkir, 2002). Following the 1999 decentralization laws local districts have gained autonomy and district heads and legislates are directly elected (Brodjonegoro, Duek and Rusli, 2010).

direct- and indirect costs of forest fires and haze pollution. The Center calculates direct costs to include damages to infrastructure and equipment from the forest fires and the cost of health treatment and fire fighting.[5] It also considers indirect costs that include losses from post-fire land reclamation, opportunity loss of production revenues resulting from fires and the negative effects of haze pollution on tourism, transport and other industries, the cost of environmental degradation and biodiversity loss, and the secondary effects of fire and haze-induced illnesses on local farmers' productivity and employment opportunities.

The Center could, however, be either myopic or captured by a local collusion group. In the myopia case it suffers from bounded rationality, where it considers in its welfare objective the tax revenues, farmer incomes and company profits. To these aggregate benefits it subtracts the direct costs of fires such as equipment and infrastructure damages and the costs of health treatment and fire fighting as well as indirect opportunity losses of the regional economy and industry. What the Center may not be able to consider is the less easily quantifiable indirect costs of future opportunity losses, environmental degradation and biodiversity loss. In the capture case a collusion group comprising local bureaucrats, business elites and companies persuade or force the central government to care only about the direct costs of forest fires and haze, which is largely localized. In both cases the central government ignores part or all of the indirect and nation-wide damages and losses from the fire and the haze.

We also examine the role, incentives and constraints of neighbouring governments ("Neighbour" or "Neighbours") which may include Singapore, Malaysia, Thailand and Brunei. These Neighbours differ in terms of their geography, economic and political interests. For the purpose of our haze game setup we use as representative neighbouring country governments Singapore or Malaysia, which are closer to the areas affected by the forest fires in Sumatra and Kalimantan. These Neighbours suffer health hazards and economic losses to their population, but also hold certain economic interests in the relevant plantation companies. Malaysia is affected by transboundary haze and pollution from Sumatra and Kalimantan but harbours a number of major plantation companies, some of which may still be involved in or benefit from the cheaper slash and burn practices in Indonesia. Singapore, amongst the most vulnerable to the haze and pollution health problems, houses financial institutions, capital market investors and transport and other companies that serve the regional plantation companies.

In line with past and current observations, the Neighbours often offer technical assistance to the Center, regardless of the latter's decision to invest in and incentivize fire and haze enforcement and

[5] See Adriani (2016) and Glauber and Gunawan (2016) for an estimation of costs, damages and losses from the Indonesian forest fires and haze pollution.

abatement, or not. Beyond such lower cost involvement, however, the neighbouring government must decide whether to invest in enforcement and abatement policies, unilaterally or jointly with the Indonesian central government. Given the intricate political economy of local bureaucrats, business elites and company interactions as well as sovereignty issues, it is conceivable that direct unilateral involvement and investment by a neighbouring country may be less effective and often not welcome.

The Neighbours weigh their payoff under unilateral intervention against a joint investment in enforcement and abatement together with the Center. In a unilateral enforcement and abatement case, the Neighbours' aggregate payoff is dominated by the full cost burden of fire and haze enforcement and abatement as well as the costs of any residual health hazards that may be unavoidable given the likely less effective unilateral action without full support of the central Indonesian and local governments. In the case of a joint investment and collaboration between the Center and local governments and the Neighbours, the costs of enforcement and abatement can be shared and the efficiency of such policies can be significantly improved. Clearly, if both the Neighbour and the Center decide not to invest in enforcement and abatement, the neighbouring economy will suffer from direct health costs and indirect economic and other opportunity losses.

In the next section 3.2 we shall examine our second-best ("SB") local capture case in detail. Local bureaucrats view the benefits to the local economy of slash and burn practices to overcompensate for the local direct costs of fire and haze. These bureaucrats are captured by local business elites (Purnomo and Shantiko et al., 2015, 2017). They collude together with interested companies to form the local collusion group, which then competes against the central government in persuading local farmers to help them clear forest lands through slashing and burning. Such local groups may under certain conditions win the contest and frustrate the central government's abatement and zero burning enforcement programs. Indirectly they will also influence the negotiations with neighbouring governments. We then introduce alternative scenarios that include farmers' outside non-land clearing employment options, a possible case of profit reimbursement to the relevant companies, and penalties on violating companies. Importantly, we analyze the impact of our common agency modelling results on the central government's transboundary bargaining, and when possible, cooperation with its Neighbours.

3.1.1 Model Setup

To set the stage, we visualize our basic fire and haze bargaining model in Table 1:

Indonesian government[1]	Neighbouring government	
	Not-Invest	Invest in enforcement & abatement
Not-Invest	$[b_b^c - h^c, -h^n]$	$[b_0^c, -c]$
Invest in enforcement & abatement	$[b_0^c - c, 0]$	$[b_0^c - (1-\gamma)c, -\gamma c]$

1. Rusli (2018)

Table 1: Fire and haze game set-up

We define b_b^c , where superscript c denotes central government and subscript b slash and burn, as the aggregate welfare benefit of company profits, farmer incomes and the corresponding tax revenues. By contrast, aggregate welfare benefit b_0^c is what the central government estimates to capture the profits, incomes and taxes under strict enforcement of zero burning policies. Slash and burn practices cost less than mechanical, zero burning land clearing methods (Gouyon and Simorangkir, 2002). As a result, plantation company profits and corresponding tax revenues are higher when at least part of the forest and peatlands are cleared through slash and burn. Thus we expect

$$b_b^c > b_0^c. \tag{1}$$

This can be inferred from Table 2, where the estimated tax, profit and income advantage of land clearing through slash and burn practices, $b_b^c - b_0^c$, is in the order of magnitude of more than USD1.7 billion (Gouyon and Simorangkir, 2002). Note that burned lands also require lower crop protection expenditures before planting, while increases in fertilizer costs are likely neglected because of their medium-term relevance.[6] The aggregate benefits of slash and burn practices for plantation companies as well as farmers, residents and local businesses is estimated to range from USD4 billion to USD8 billion. Here we use published estimates, whereas for private, community and government (i.e. non-plantation and forestry company) lands we assume either own use or

[6] Gouyon and Simorangkir (2002).

subsequent sale of the burned and cleared lands to other companies.[7]

Payoff estimates (USD billion)			
Cost of fire and haze:[1]		Incremental profits slash and burn[3]	
Direct costs and damages (h^l)	2.2	Peat swamps (37%)	1.2
Indirect losses (agro, tourism and industry, biodiversity)	13.9	Forest lands (63%)	0.5
Direct and indirect costs & damages (h^l)	16.1	Incremental company profits (b_b^c-b_0^c)	1.7
Benefits of slash and burn[2]		Cost of enforcement and abatement[4]	
Companies (34%)	2.7	Legal and enforcement (c_a)	0.5-1.0
Private, community, government lands (66%)	1.5-5.3	Maximum profit reimbursement (b_b^c-b_0^c)	1.7
Total benefits (b_b^c)	4.2-8.0	Compensation to farmers (w)	1.5
		Total enforcement/abatement (c)	3.7-4.2

1. World Bank (2016). Direct costs incl. damages to agriculture, losses of food crops, costs of healthcare and firefighting.
2. Purnomo et al. (2015). Rusli (2018) assumes same profits for oil palm and plantation companies.
3. Gouyon and Simorangkir (2002). Rusli (2018) assumes profit split 37% peat swamps, 17% forest for timber and 46% forest for oil palm.
4. Rusli (2018).

Table 2: Fire and haze cost-benefit estimates

Next we designate c as the total costs of fire and haze enforcement and abatement to be incurred by either the Indonesian central government or the neighbouring country government. It may have three components: (i) the direct abatement costs c_a of monitoring, extinguishing forest fires and enforcing the rules, (ii) the wages, incentives and subsidies ("compensation") to be offered to farmers for engaging in legal, mechanical land clearing and other agricultural works, w^c, plus (iii) the estimated partial or full profit reimbursement π to local businesses and plantation companies for not burning.[8] Thus the total cost of enforcement and abatement equals

$$c = c_a + w^c + \pi. \tag{2}$$

In our common agency setup below we start with the case of enforcement and abatement without profit reimbursement π, an assumption that shall be subsequently relaxed. We estimate the aggregate enforcement and abatement costs including monitoring and policing costs and farmers' compensation, but excluding any profit compensation to businesses, to reach about USD2.0-2.5 billion. In our FB case we assume that the aggregate enforcement and abatement costs and the effectiveness of the abatement efforts to induce zero burning are the same regardless of whether these are implemented by the Indonesian or the neighbouring government.

We define $h^{tot} = h^c + h^n$ as the aggregate direct and indirect damages and losses from forest burning and the resulting haze pollution. This comprises the aggregate costs for the Indonesian economy and government, h^c, which is depicted in Table 2 and estimated by Glauber and Gunawan (2016) to reach more than USD16 billion. The neighbouring countries' direct healthcare

[7] We interprete per hectare benefit estimates from Purnomo et al. (2015, 2017).

[8] In the common agency section below we introduce compensation to be paid to farmers by Local Group, w^l.

expenditures and losses to industry and tourism, h^n, are harder to quantify. Nevertheless, previous numbers from the late 1990s already estimated costs in the order of magnitude of up to USD2 billion, which today, given population and economic growth as well as inflation, would be multiples higher.[9] We thus assume, plausibly, that such enforcement and abatement costs are lower than the direct and indirect costs of allowing forest fires and slash and burn techniques to continue unabated:[10]

$$h^{tot} > h^c > h^n > c. \tag{3}$$

Note that we assume that h^n is strictly higher than c. First, profit reimbursement, although examined in below model, is highly unlikely. Without profit reimbursement the enforcement and abatement costs are lower than the neighbour's cost and damages (see Table 2). Second, the neighbouring government is likely to perceive the health and economic costs of fire and haze to its society, including the associated indirect domestic political-economy costs, to outweigh the cost of investing in enforcement and abatement.

3.1.2 Payoffs and Solutions

On the basis of this setup with high aggregate direct and indirect costs, damages and losses and modest enforcement and abatement costs, the payoff structure of this game, assuming the two players bargain simultaneously, looks as follows: When neither government chooses to invest in enforcement and abatement, {Indonesia, neighbour} = {Not-invest, Not-invest}, the forest fires and haze remain unchecked and the payoffs are $[b_b^c - h^c, -h^n]$. Indonesia keeps the benefits of forest burning but incurs heavy costs, damages and losses to its citizens, economy and the environment, while the neighbouring government suffers the health and economic costs of the transboundary haze. By contrast, if the Indonesian government decides to unilaterally invest in enforcement and abatement, and is effective at it, {Invest, Not-invest}, it reduces its domestic benefits and incurs the aggregate costs of enforcement and abatement, yet avoids the costs of damages and losses from the fires and haze. The payoff shall be $[b_0^c - c, 0]$ where the Neighbour enjoys a haze-free sky without incurring the costs, apart from low cost technical cooperation and political coordina-

[9] Taccioni (2003) summarizes the ADB and ISAS estimates, whereby the ADB indicates that the indirect environmental and carbon emission losses to neighbouring countries i.e. Malaysia and Singapore make up the largest proportion of the neighbouring economies' losses from the Indonesian haze.

[10] Recall that the estimated aggregate damages and losses includes not only direct costs but also indirect losses. Direct costs cover the costs of fire fighting and healthcare expenditures as well as damages and losses to agricultural and forestry lands and equipment. Indirect costs include losses to the regional economy including the transport, industry and tourism, environmental and biodiversity losses as well as indirect loss in future income and wages due to fire- and haze-related sicknesses.

tion efforts (which we ignore). Should the neighbouring government decide to unilaterally invest, {Not-invest, Invest}, however, the payoff shall be $[b_0^c, -c]$. Last but not least, if both governments decide to jointly invest and share the costs of enforcement and abatement, {Invest, Invest}, the payoff changes to $[b_0^c - (1-\gamma)\, c, -\gamma c]$, where γ is the fraction of enforcement and abatement costs that the neighbouring government bears if the Indonesian government was prepared to cooperate and jointly invest.

Now applying the assumptions on benefits (1) and costs (3), we derive the relative payoffs

$$(b_0^c - c) > (b_b^c - h^c) \text{ and } b_0^c > b_0^c - (1-\gamma)\, c \tag{4}$$

for the Indonesian government, and

$$c < h^n \text{ and } \gamma c > 0 \tag{5}$$

for the neighbouring country government. We observe that the Indonesian government would engage in enforcement and abatement and punish slash and burn practices across the country if it believes that the neighbouring country government will not invest in enforcement and abatement. However, if it thinks that the neighbouring government may invest in enforcement and abatement, the Indonesian government is incentivized not to invest, and will maintain status quo. On the other hand, the neighbouring country government is forced to invest in enforcement and abatement if the Indonesian government is expected to not invest; it will not invest if the Indonesian government shows any willingness to invest.

This results in a classic "game of chicken" with its three Nash equilibria, comprising two pure- and one mixed strategies. The first pure one, {Not-invest, Invest} results in payoffs $[b_0^c, -c]$ as per Figure 1, and represents the equilibrium where the Indonesian government will not invest if the neighbouring government is willing to invest. The second pure Nash equilibrium, {Invest, Not-invest} with payoffs $[b_0^c - c, 0]$, describes the outcome where the Indonesian government will invest if the Singaporean government credibly commits to not investing. The third, mixed Nash equilibrium will then be joint enforcement and abatement, {Invest, Invest}. The results can be summarized as follows.

Proposition 1 *Suppose that land clearing through slash and burn is more profitable, $b_b^c > b_0^c$, and that the aggregate health, economic and environmental damages and losses are sufficiently high, such that $h^{tot} > h^c > h^n > c$. Then, the bargaining between a benevolent central government of Indonesia and its neighbouring country government results in a game of chicken. This game has two pure Nash equilibria*

$$\{\Omega^c, \Omega^n\}_{FB} = \{\textit{Not-invest, Invest}\}, \{\textit{Invest, Not-invest}\}, \tag{6}$$

plus one mixed cost-sharing strategy

$$\{\textit{Invest, Invest}\}.$$

Thus either government invests in abatement only if the other refrains from investing or credibly signals its reluctance, or vice versa, unless they both agree to jointly share the costs of abatement. Furthermore, all three solutions are efficient, since the aggregate payoff of both parties is maximized and total welfare of mechanical land clearing without burning is higher than the case of slash and burn,

$$(b_0^c - c) > (b_b^c - h^c) - h^n.$$

Proof. Derive from (4) and (5). ■

In Appendix 1 we summarize extensions to the basic game of chicken setup, where it is assumed that the central government might suffer from myopia, be itself captured or when the neighbouring government cannot efficiently unilaterally invest in enforcement and abatement. We now focus on the local capture and common agency problem.

3.2 Principals Competition Model

We start our common agency problem with a unified local collusion group (the "Local Group") and assume zero profit reimbursement from central government. We distinguish three parties and examine the participation i.e. budget and incentive constraints of the Indonesian central government, the Local Group and local farmers. Following this analysis we examine the comparative payoffs and the farmers' compensation and incentives. We later introduce profit reimbursements and possible penalties, farmers' outside employment options and, in particular, study how the local common agency problem affects the central government's transboundary bargaining with its Neighbours.

3.2.1 Central Government versus Local Group

Central Government Incentives We start with the case where the Indonesian central government invests in abatement and its Neighbour does not. Following (4) this is the case whenever $(b_b^c - h^c) \leq (b_0^c - c_a) - w^c$, where we have introduced the superscript c in w^c to designate the central government's compensation payments to the farmers.[11] The central government's incentive

[11] Note that we assume $c = c_a + w^c$ for now, i.e. without profit reimbursement factor π. Moreover, given the distinct objectives of the central government (zero burning) versus the local collusion group (slash and burn), we simplify $w_b^l \equiv w^l$ and $w_0^c \equiv w^c$ and ignore the subscripts from here on.

constraint to offering compensation to farmers, as alternative income in lieu of them engaging in slash and burn practices, is thus

$$w^c \leq (h^c - b_b^c) + (b_0^c - c_a)\,.$$

The central government wishes to compensate farmers as long as it costs less than the sum of the damages and losses from burning, net of the tax revenues and profits gained from slashing and burning, plus the net benefit of enforcement and abatement. The higher the net aggregate direct and indirect damages and losses from burning and the higher the net benefit of enforcing and not burning, the more the central government would be able to compensate and incentivize farmers and residents. Assuming that central government has sufficient funds to compensate the farmers, the incentive constraint can be rearranged to yield the central government budget constraint

$$w^c \leq (h^c - c_a) - (b_b^c - b_0^c)\,. \tag{7}$$

Thus the higher the incremental tax, profit and income benefits of slashing and burning, which we recall is captured under $(b_b^c - b_0^c)$, the less can the central government afford to spend incentivizing farmers and residents to not engage in slashing and burning.

Local Group Incentives Local bureaucrats captured by profit-oriented local business elites and plantation companies conduct their own cost-benefit analysis. They compare the net benefit of slash and burn techniques of land clearing with other more environmentally benign but costlier land clearing methods such as purely mechanical clearing. Assuming this collusive arrangement aligns the various local stakeholders' interests with the local government bureaucrats, their collective incentive constraint can be described as $\left(b_b^l - h^l\right) - w^l \geq b_0^l$. Here we introduce the superscript l to refer to the Local Group comprising bureaucrats, relevant plantation companies and the business elites . The latter "brokers" typically organize and lead such a local business-bureaucrat collusion groups (Purnomo et al., 2015, 2017).

Thus w^l represents the compensation paid by the Local Group to incentivize farmers to help them clear the forest and peatlands through slashing and burning. The local bureaucrat will endorse slash and burn activities if the profit to the Local Group, net of the direct health and economic damage and losses to the local populace and the compensation paid to farmers in return for slashing and burning the agreed forest and peatlands, is higher than the local taxes and company profits of not burning at all and clearing the local lands mechanically. Another way to describe this is that, when the local business elites and companies have higher profit expectations from slashing

and burning and a larger budget to "compensate" the local bureaucrats, the local bureaucrats will endorse and the Local Group will choose such an outcome.

The Local Group's incentive constraint can be rewritten as function of the incremental tax, profit and income benefits of burning. This yields its budget constraint

$$w^l \leq \left(b_b^l - b_0^l\right) - h^l. \tag{8}$$

We therefore anticipate that the compensation that the Local Group can afford to pay to farmers and residents for slashing and burning increase with the incremental benefit and profits of burning local forests and peatlands, and decrease with the local health and economic damages and losses from burning.

The company profits, local taxes and levies and farmers' incomes and compensation is generated and enjoyed mainly by the Local Group, thus benefitting the captured local bureaucrats, relevant plantation and timber companies and farmers. From the perspective of a utilitarian, benevolent central government, a portion of the income taxes levied on local company profits and farmers' compensation goes to the central budget. Following that, in accordance with Indonesia's balanced allocation fund (DAU and DAK) the central government transfers a large part of such income taxes back to the local governments.[12] Moreover, the central government takes into account all the surplus enjoyed by local collusion group in its own surplus and welfare equation, since most or all of the Local Group members are citizens as well. Thus we assume that the aggregate welfare benefits to the country, from the central government's perspective, is largely similar to the benefits to the Local Group.[13]

As a result we can assume and simplify our notations

$$b_b^l \approx b_b^c \equiv b_b \text{ and } b_0^l \approx b_0^c \equiv b_0, \tag{9}$$

where the aggregate benefits of burning and zero burning continue to satisfy (1), $b_b > b_0$.

Farmers' Incomes and Compensation Farmers choose between engaging in slash and burn works for a wage or compensation w^l, and zero burning mechanical clearing for a wage or compensation w^c. We also introduce an effort variable for the farmers, depending on whether they engage

[12] The literature on fiscal decentralization and center-local transfers in Indonesia is broad and deep. For a simple discussion on the general allocation fund (DAU) see, for example, Ford and Brodjonegoro (2004), Fitrani et al. (2005), Duek and Rusli (2010) and Rusli and Vermeulen (2019).

[13] We show later that relaxing this assumption decreases the DAU allocation back to the district, which in turn expands the range of solutions where the central government succeeds in compensating and motivating farmers to choose legal, zero-burning mechanical land clearing work.

in slashing and burning e_b or mechanical and other non-burning land clearing or other activites e_0. Thus the incentives of farmers can be defined as

$$\max\left\{w^c - e_0, w^l - e_b\right\}, \tag{10}$$

where farmers simply aim to maximize their incomes net of efforts. We shall later look at various scenarios of e_b versus e_0, and will look into other, non land clearing employment and entrepreneurial alternatives ("Outside Options") for the farmers.

Farmers' Income Analysis Local farmers compare their net incomes i.e. compensation minus efforts that they may gain from slashing and burning the forest and peatland areas, $w^l - e_b$, for the benefit of the Local Group, and the compensation they may get from the central government minus the efforts to engage in legal, non-burning and other income-generating activities, $w^c - e_0$. Local farmers maximize net incomes (10) by comparing the compensations that the central government and the Local Group can offer. Making use of the maximum compensations (7) and (8) and introducing the farmers' effort levels of slashing and burning versus mechanical clearing or other employment yields

$$w^c - e_0 \leq (h^c - c_a) - (b_b - b_0) - e_0 \tag{11}$$

and

$$w^l - e_b \leq (b_b - b_0) - h^l - e_b. \tag{12}$$

The comparative net compensation levels can be visualized as in Figure 2:

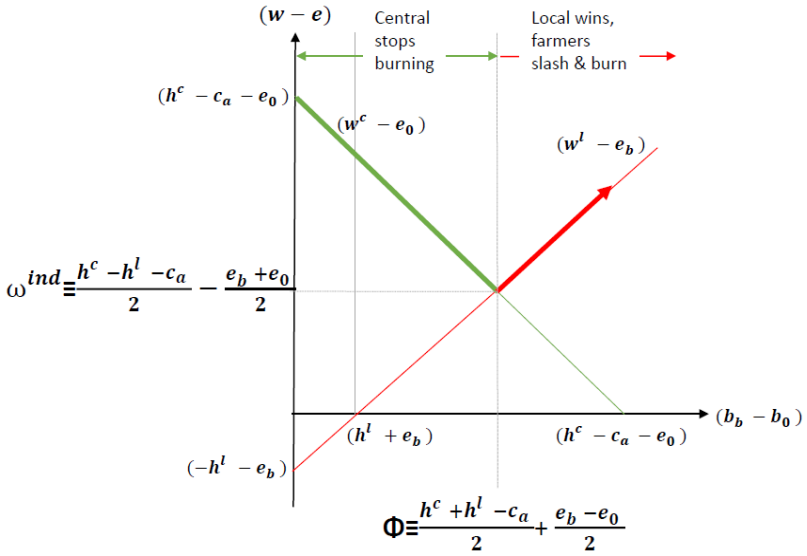

Figure 2: Farmers' net income

The farmers will choose the highest net compensation they could earn. First, larger incremental benefits of slashing and burning over enforcement and abatement will make it easier for the Local Group to raise more money to compensate farmers to continue slashing and burning local forests and peatlands. Second, the lower the incremental benefits vis-a-vis the aggregate damages and losses from slashing and burning and the damages and losses from the haze, the more the central government can afford to pay and compensate the farmers and residents for their efforts to not burn the forests. Third, if the incremental benefits of burning is too low, the Local Group would not be in a position to persuade and compensate the farmers to expend the effort to slash and burn. More formally we obtain:

Proposition 2 *Suppose the central government's and the Local Group's budget constraints, (12) and (11), are binding. Local farmers are then indifferent and receive equal compensation, net of their effort, between engaging in slashing and burning or conducting mechanical, zero burning land clearing, at the "Indifference Point"*

$$\Phi \equiv (b_b - b_0)_\Phi = \frac{\left(h^c + h^l - c_a\right)}{2} + \frac{(e_b - e_0)}{2}. \tag{13}$$

At Φ the Center offers to pay farmers a compensation $w^c = \frac{(h^c - c_a)}{2} - \frac{h^l}{2} - \frac{(e_b - e_0)}{2}$ to conduct zero burning mechanical land clearing work, while the Local Group could compensate farmers with $w^l = \frac{(h^c - c_a)}{2} - \frac{h^l}{2} + \frac{(e_b - e_0)}{2}$ to slash and burn. The net compensation to the farmers, the "Indifference Compensation", is

$$\omega_{ind} \equiv \frac{\left(h^c - h^l - c_a\right)}{2} - \frac{(e_b + e_0)}{2}.$$

Proof. At Φ farmers receive the same compensation, net of their efforts, for slashing and burning or mechanical clearing, $w^l - e_b = w^c - e_0$. Equating (11) and (12) and rearranging results in (13). Substituting the latter into (7) respectively (8) then results into the respective compensations payments w^c and w^l. ■

When the budget constraints bind, both Center and Local Group are ready to pay their maximum respective compensations to farmers. We find that, if the incremental benefits of slashing and burning are larger than the Indifference Point, $(b_b - b_0) > \Phi$, the Local Group pays more and farmers engage in slash and burn. By contrast, if the incremental benefits are lower, $(b_b - b_0) \leq \Phi$, the central government convinces the farmers to not engage in slashing and burning and to seek other employment or work on other mechanical methods of land clearing. However, when the incremental benefit of burning is so low such that it falls below the local damages and losses from burning, the Local Group will choose not to engage in slash and burn at all,

$$w^l \leq (b_b - b_0) - h^l \leq 0.$$

The central government can now minimally incentivize the farmers and residents to adhere to the rules and regulation and refrain from slashing and burning.

The Indifference Point shifts to the right, making it easier for the central government to motivate zero burning, when the total costs and damages h^c and h^l increase or the cost of enforcement and abatement c_a decreases. The effort expended by farmers and residents plays an important role here. If the farmers' and residents' effort is lower for slashing and burning than for zero burning mechanical land clearing or doing other work, $(e_b - e_0) \leq 0$, then it becomes easier for the Local Group to win the contest against the central government, even at lower incremental benefits of burning. This is obviously unfavourable to the central government, which can only convince the farmers and residents to not slash and burn when the incremental benefits of burning are even lower.

Furthermore, considering possible bounded rationality or capture of the central government by the Local Group[14], we observe that the Center's budget constraint tightens and it is harder to prevent slash and burn activities:

Corollary 1 *When the central government is captured or due to bounded rationality does not observe the entire indirect costs and damages from slashing and burning, the effective cost and damage it observes is lower,* $h^l \leq h^{eff} < h^c$. *The Indifference Point* Φ *decreases because* $\partial\Phi/\partial h^c > 0$ *from (13). It is unlikely that the central government ignores the costs and damages observed by the local government and its collusion partners.*

Our results also offer a possible explanation to Edwards et al.'s (2020a) findings, where they have not yet found significant benefits from fiscal incentives. Our model predicts that only sufficiently high compensation can persuade farmers to avoid slashing and burning. Additionally, the Center possesses a certain power to potentially decrease its annual allocation payments to the district government out of the general allocation fund (DAU). This will reduce the effective incremental benefits of burning observed and enjoyed by the Local Group, as

$$b_b^l - b_0^l < b_b^c - b_0^c \equiv b_b - b_0.$$

Thus relaxing assumption (9) decreases the perceived incremental benefits from slashing and burning $b_b^l - b_0^l$. The Center wins the contest at higher actual incremental benefits, $b_b^c - b_0^c \equiv b_b - b_0$.

We shall now examine several additional scenarios relevant to this competing principals model.

[14] See also Appendix 1.

3.2.2 Abatement Costs and Reimbursement for Lost Profits

The enforcement and abatement costs c_a can be large when the terrain is very difficult, information on and monitoring of local forest and landbank boundaries and fires is insufficient or hampered, the Local Group creates physical and information roadblocks, etc. We know from (7) that higher enforcement and abatement costs tighten the central government's budget constraint. As a consequence, Proposition 2 also implies that higher costs of enforcement and abatement decrease the farmers' Indifference Point, as $\partial\Phi/\partial c_a < 0$. This makes it more difficult for the Center to outbid the Local Group, and farmers are more inclined to engage in slash and burn work.

Occasionally, there could be instances where the Local Group might be so powerful such as to be able to negotiate at least partial reimbursement for profits it may lose from having to agree to mechanical or other non-burning land clearing methods.[15] In this case total enforcement and abatement costs (2) would include profit reimbursement, resulting in

$$c = c_a + w^c + \pi,$$

where we reintroduce the profit reimbursement term π. This profit reimbursement can be reasonably assumed to be smaller than the net benefit of slashing and burning, $\pi \leq (b_b - b_0)$. There are several ways to estimate and introduce this profit reimbursement into our model. First, a finite reimbursement amount $\overline{\pi}$ will reduce the central government budget constraint (7). The farmers' Indifferent Point decreases to

$$\Phi = \left(h^c + h^l - c_a - \overline{\pi}\right)/2 + (e_b - e_0)/2.$$

In this case the farmers' net compensation from the Center (11) decreases as the Center's budget constraint (the green downward sloping line) in Figure 2 shifts down. Second, suppose that $\widetilde{\pi}$ was proportional to the incremental benefit of slash and burn, say with a proportionality factor $\rho \in [0, 1]$. We observe that $\widetilde{\pi} = \rho\,(b_b - b_0)$ and upon substitution into (11) the Center's budget constraint retains its y-axis intercept but rotates downwards i.e. clockwise as the tangent $\partial\,(w^c - e_0)/\partial\,(b_b - b_0) = -1$ decreases to $-(1 + \rho)$. Both scenarios with profit reimbursement decrease the farmers' Indifference Point and make it harder for the central government to outbid the Local Group. We observe:

Corollary 2 *Suppose that the Center's total cost of enforcement and abatement includes profit reimbursement to the Local Group, $c = c_a + \pi + w^c$. In case of a fixed profit reimbursement $\overline{\pi}$,*

[15] We initially ignore profit reimbursement π based on the premise that, as long as central government can incentivize farmers and residents not to engage in slash and burn practices, the local businesses and plantation companies can not start their slash and burn programs.

the maximum fixed profit reimbursement will not exceed the incremental net benefit from slashing and burning, $\overline{\pi} \leq b_b - b_0$. If the profit reimbursement is proportional to the incremental benefit of slash and burn, $\widetilde{\pi} = \rho\,(b_b - b_0)$, then the Indifference Point decreases to

$$\Phi\,(\rho) = \frac{\left(h^c + h^l - c_a\right)}{2\,(1+\rho)} + \frac{(e_b - e_0)}{2\,(1+\rho)}.$$

Proof. From (13) we observe that $\partial\Phi/\partial c_a < 0$ and infer that $\partial\Phi/\partial\pi < 0$. ■

Higher costs of enforcement and abatement as well as profit reimbursement demands by the Local Group reduce the Indifference Point. It becomes harder for the Center to outbid the Local Group.

3.2.3 Enforcement and Penalties on Colluding Companies

Instead of offering compensation to plantation companies for foregoing incremental profits from slashing and burning, it is more cost-effective for central government to conduct strict monitoring and enforcement. Companies caught engaging in illegal slash and burn-related activities can then be forced to pay penalties and fines. The expected penalty income reduces the overall enforcement and abatement costs, thus partially compensating for the monitoring, fire fighting and enforcement costs.

Some of the medium and large Indonesian and international plantation companies have offices, headquarters, banking relationships or are listed on the stock exchanges of Singapore and or Malaysia. Here, as part of these neighbouring government's negotiations and discussions with the Indonesian central government, the former may be able and willing to exert some pressure on the relevant plantation companies. It is indeed in these Neighbours' interest to catch and punish the plantation companies that violate the no-burning laws and regulations. Moreover, the Center may also directly penalize the violating companies. We find:

Corollary 3 *When the Center is able to identify and impose penalties on the violating companies or when the Neighbours can control plantation companies through capital markets and tax policies within their respective jurisdiction, a finite mean penalty $\overline{\theta}$ increases the Indifference Point to*

$$\Phi = \frac{\left(h^c + h^l + \overline{\theta} - c_a\right)}{2} + \frac{(e_b - e_0)}{2}.$$

It is now easier for central government to outbid the Local Group for the purpose of compensating farmers for not burning.

Proof. The Local Group's budget constraint (12) decreases as the Local Group's costs from fire and haze increases from h^l to $h^l + \overline{\theta}$. ■

As part of the local collusive groups, these companies would consider the expected value of such penalties as additional costs that reduce the benefits of slashing and burning. In this case the Local Group's budget constraint (8) decreases by a mean penalty $\overline{\theta}$. As a consequence, the farmers' net compensation from the Local Group (12) decreases, the Local Group's budget constraint (upward-sloping red line) in Figure 2 decreases and Φ increases by $\overline{\theta}/2$. Note, however, that for penalties to be effective, the central government (and its neighbours) must have accurate information on the ownership of and activities in the relevant acreages.

3.2.4 Farmers' Outside Options

We now introduce additional employment opportunities for farmers ("Outside Option"), which do not involve any land clearing activities. These could include employment in local companies and industries or other entrepreneurial activities. The farmers' objective function (10) now changes to

$$\max \left\{ w^c - e_0, w^l - e_b, w^o \right\}. \tag{14}$$

Here we introduce w^o as the net wage income of farmers, after accounting for the corresponding farmers' efforts exerted to engage in the outside employment or entrepreneurial work. The resulting relative incomes of the farmers can now be illustrated as follows:

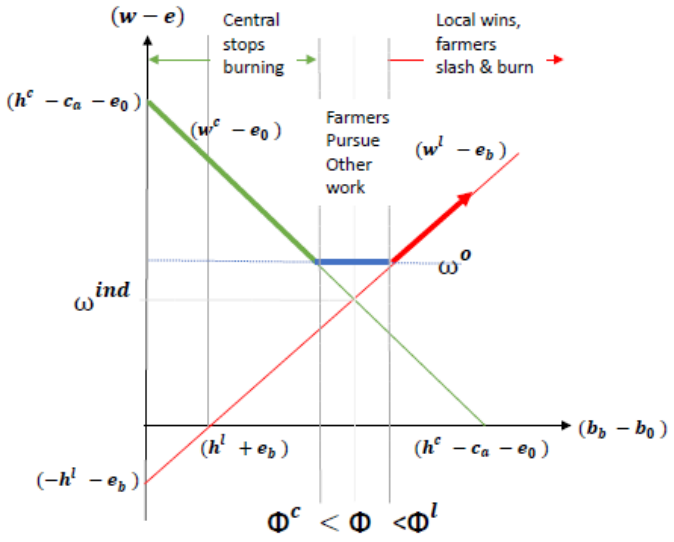

Figure 3: Farmers' net income incl. Outside Option

Note in Figure 3 that the Outside Option net wage line w^o could lie below or above the original "indifferent compensation" ω_{ind}. If $\omega^o \leq \omega_{ind}$ the outside net wage does not change our original result. However whenever the outside wage increases to a higher level such that $w^o > \omega_{ind}$, then it becomes more difficult for the Local Group to incentivize farmers to help them clear the land through slashing and burning. We obtain:

Proposition 3 *Suppose farmers face an alternative income source involving non-land clearing employment such as industrial and retail employment or entrepreneurial activities ("Outside Option"). Then the Indifference Point* Φ *remains unchanged when the outside wages remain below the indifference compensation,* $\omega^o \leq \omega_{indiff} = \left(h^c - h^l - c_a\right)/2 - \left(e_b + e_0\right)/2$*, but splits into a "Center's Indifference Point"*

$$\Phi^c \equiv (b_b - b_0)_{\Phi^c} = (h^c - c_a - e_0) - \omega^o \equiv \Phi_A = 2\Phi - \left(h^l + e_b\right) - \omega^o$$

and a "Local Group's Indifference Point"

$$\Phi^l \equiv (b_b - b_0)_{\Phi^l} = \left(h^l + e_b\right) + \omega^o \equiv \Phi_B = 2\Phi - (h^c - c_a - e_0) + \omega^o$$

when $\omega^o > \omega_{indiff}$.

Proof. Φ^c and Φ^l are found by equating (11) with ω^o and respectively (12) with ω^o, and correspondingly substituting the expression for Φ from (13). ■

If the incremental benefits of slashing and burning are larger than the Local Group's Indifference Point, $(b_b - b_0) > \Phi^l$, the Local Group wins and succeeds in motivating the farmer to slash and burn. By contrast, when the incremental benefits from burning are smaller than the Center's Indifference Point, $(b_b - b_0) < \Phi^c$, the Center's budget is likely to be sufficient to motivate farmers to engage in mechanical land clearing instead of slashing and burning. In the intermediate benefits range, when $\Phi^c \leq (b_b - b_0) \leq \Phi^l$, the farmers' Outside Option prevails, the Local Group loses while the Center does not have to compensate the farmers since farmers do not wish to engage in slashing and burning. As a consequence, the higher the income potential of farmers from non-land clearing and other employment or entrepreneurial activities, the higher the incremental benefits and profits of slashing and burning must be to enable the Local Group to provide local farmers sufficient motivation and compensation.

This result clearly supports the findings of Edwards et al. (2020b). More effective education and industrialization can help farmers benefit from other employment opportunities by increasing the wages they could earn from outside employment options. By contrast, farmers in remote and less developed regions are more likely to engage in slashing and burning, where it is cheaper for local collusion groups to engage and compensate them.

3.3 Impact on the Fire and Haze Game of Chicken

We now return to examine the impact of the local common agency problem and the farmers' choices on the original game of chicken of bargaining between the Center and its Neighbours, our second best ("SB") case. We again examine the payoffs of the Center vis-a-vis its Neighbours. When the incremental benefits from burning are lower than the Indifference Point,

$$b_b - b_0 \leq \Phi,$$

only one of the three Nash solutions to the game of chicken is feasible,

$$\{\Omega^c, \Omega^n\}_{SB,low} = \{\text{Invest, Not-invest}\}.$$

Here we use the suffix "low" to characterize situations where either the incremental profits from burning are low or the costs of enforcement and abatement are low. Observing the Center's active contest with the Local Group, the Neighbour always free rides. Only {Invest, Not-invest} remains feasible. The resulting aggregate payoff $(b_0 - c)$ is efficient, just like in the FB case.

By contrast, recalling (13) we gather that whenever the inequality

$$b_b - b_0 > \Phi(c_a, \pi)$$

holds, the Center will lose against the Local Group. This is possible when the incremental profits from burning are high, the costs of enforcement and abatement are high or the Local Group is able to demand high profit reimbursement. Of the three possible solutions to the game of chicken (6) between the Center and its Neighbour, only the joint investment equilibrium remains feasible,

$$\{\Omega^c, \Omega^n\}_{SB,high} = \{\text{Invest, Invest}\}.$$

The solution {Invest, Not-invest} is not feasible as here the Local Group outbids the Center. At the same time, {Not-invest, Invest} is also not feasible. The reason is that, when the Center does not invest in enforcement and abatement, the Neighbour can only invest when the damages and costs to the neighbouring country are higher than the total cost of abatement (2), $h^n \geq c_a + w^n + \pi$.[16] This inequality can only be satisfied if the Neighbour is able to outbid the Local Group,

$$h^n \geq c_a + w^l - (e_b - e_0) + \pi, \tag{15}$$

where we make use of the farmers' break-even net income, $w^n - e_0 = w^l - e_b$, similar to the proof to Proposition 2 above. However, (15) cannot be satisfied. From (3) we know that the Neighbour

[16] Here we introduce the compensation that the Neighbour will offer to the farmers to not slash and burn, w^n.

can never offer higher compensation (to the farmers) compared to the Center, because the costs and damages of the transboundary haze to the Neighbour is always lower than the total direct and indirect costs and damages observed by the central government. Thus when the Center cannot outbid the Local Group, neither can the Neighbour.

The only possibly remaining solution to this SB case is therefore joint investment in enforcement and abatement,

$$\{\Omega^c, \Omega^n\}_{SB,high} = \{\text{Invest, Invest}\}.$$

Now the suffix "high" characterizes high incremental profits from burning and or high enforcement and abatement costs. The Center must seek the cooperation and support of its Neighbours. First, the Neighbour helps mobilize additional managerial and technical resources, possibly helping to reduce the cost of enforcement and abatement c_a, which include the cost of monitoring, preventing and fighting fires. Second, the Neighbour will ease the budget constraint of the Center, since (7) will now include the potential damages and costs to the neighbouring government h^n. The resulting combined Center's and Neighbour's budget constraint thus expands to

$$w^c \leq (h^c + h^n - c_a) - (b_b^c - b_0^c).$$

Clearly this shifts the Center's budget constraint upwards, thus shifting the Indifference Point to the right i.e. to higher incremental benefit levels of slashing and burning. Formally:

Proposition 4 *When the benefits from burning and enforcement and abatement costs are low and the Center wins the contest,* $b_b - b_0 \leq \Phi(c_a, \pi)$, *only one Nash equilibrium is feasible,*

$$\{\Omega^c, \Omega^n\}_{SB,low} = \{\textit{Invest, Not-invest}\},$$

since the Neighbour free-rides on the central government. However, when the benefits from burning and enforcement abatement costs are high such that $b_b - b_0 > \Phi(c_a, \pi)$, *the Center is outbid by the Local Group. Only one solution of the game of chicken is feasible,*

$$\{\Omega^c, \Omega^n\}_{SB,high} = \{\textit{Invest, Invest}\}$$

and a higher "Cooperative Indifference Point" is observed

$$\Phi^{coop} \equiv \frac{\left(h^c + h^n + h^l - c_a\right)}{2} + \frac{(e_b - e_0)}{2} > \Phi.$$

The Center and Neighbour jointly outbid the Local Group and prevent slashing and burning when

$$\Phi^{coop} \geq b_b - b_0$$

and lose otherwise. The "Cooperative Indifference Compensation" is higher,

$$\omega_{ind}^{coop} \equiv \frac{\left(h^c + h^n - h^l - c_a\right)}{2} - \frac{(e_b + e_0)}{2} > \omega_{ind},$$

and the total farmer' compensation increases to

$$w^{coop} = \frac{(h^c + h^n - c_a)}{2} - \frac{h^l}{2} - \frac{(e_b - e_0)}{2} > w^c.$$

The aggregate payoffs under FB and SB are efficient at $(b_0 - c)$.

Proof. The prove is discussed above. ■

The Center and its Neighbours cooperate to jointly invest in enforcement and abatement. They pool their resources and increase their compensation to farmers. The Indifference Point and the Indifference Compensation increase. The Center benefits from the Neighbour's help and together they can offer farmers higher combined compensation. However, the benefits from burning is too high, such that $\Phi^{coop} < b_b - b_0$, the Local Group outbids them still and the Center and its Neighbour may have to refer to other financing partners to expand on their combined budget constraint.

Finally, it is noteworthy that the only scenario under which the Neighbour may be compelled to unilaterally invest in enforcement and abatement is when the benefits from burning are low, the costs of enforcement and abatement is low and the Local Group cannot demand profit reimbursement, while concurrently the Center credibly signals to the Neighbour that it has no intentions to invest. This is an unlikely outcome however, as the Neighbour observes an active contest between the Center and Local Group. We summarize:

Corollary 4 *Even when the Neighbour's budget constraint is satisfied,*

$$h^n \geq c_a + (b_b - b_0) - h^l - (e_b - e_0),$$

then Neighbour will always choose to free ride.

Proof. The Neighbour's budget constraint is derived from (15) while assuming that the Local Group's budget constraint (8) is binding. ■

This inequality is likely when the benefits from burning and the costs of enforcement and abatement are low, and the Local Group cannot demand any profit reimbursement. We find that the Neighbour will always free ride on the Center and may not even wish to cooperate. The reason is that, first, the Indonesian central government budget is also satisfied whenever $h^c > h^n$, and second, the Neighbour, watching the active contest between the Center and the Local Group, knows that the Center will enforce and actually is likely to win the contest. Which brings us back to the proposition 3 above.

3.4 Multitask Multiprincipal Model

The competing principals model describes a contest between the Center and the Local Group, where either one wins or loses. It does not explicitly consider partial outcomes, where a portion of a region's forest and peatlands is slashed and burned, while the remaining acreage is mechanically cleared without any burning.[17]

We now derive a multitask multiprincipal model which not only allows for partial outcomes, but also simultaneously introduces direct penalties in the form of negative compensation paid by the Center for any illegal slash and burn outcome.[18] In our dual-task dual-principal common agency setup we consider two principals, the central government (superscript c) versus the local collusion group (superscript l), and exactly two tasks, slash and burn (subscript b) versus zero burning mechanical land clearing (subscript 0).[19] Thus we have $m = 2$ tasks and $n = 2$ principals. Each principal benefits more from one of the tasks, while benefiting less or suffering from the other task. The principals' collective benefit becomes

$$\mathbf{b} = \mathbf{b}^c + \mathbf{b}^l = \begin{pmatrix} b_0 - c_a \\ b_b - h^c \end{pmatrix} + \begin{pmatrix} b_0 \\ b_b - h^l \end{pmatrix}, \tag{16}$$

where we use our previous notations for the net benefits, costs and damages to the central government respectively to the local collusion group. We model that profits from both zero burning mechanical land clearing (which are lower) and from slashing and burning (which are higher) are enjoyed by the Local Group. In the case of slashing and burning, the Local Group also suffers the direct costs and damages from fire and haze (which are much lower than the indirect costs and damages). The Center's welfare function includes the profits enjoyed by the Local Group -whose members are also citizens and residents of the country- including the associated local tax revenues. From these profits and taxes the central government subtracts the corresponding costs and expenditures: Total direct and indirect costs and damages from slashing and burning, or the costs of enforcement and abatement in the case of mechanical land clearing without burning. This is consistent with our assumption (9) that both the Center and the Local Group observe the same

[17] Two possible scenarios are conceivable: First, the farmers sort themselves into two groups, each allocated to distinct parts of the forest and peatlands acreage. In one part legal mechanical land clearing is conducted, while in the other area farmers slash and burn. Second, farmers as a collective split their time and energy ("effort") into mechanical land clearing and slashing and burning in the same or adjacent acreage.

[18] For the original, more detailed model derivation see Appendix 2.

[19] We make use of Dixit's (1996) multitask common agency model. See also for example Holmstrom and Milgrom's (1991) multitask model, Bernheim and Whinston's common agency model (1986), Grossman and Helpmann's (1994), Epstein and O'Halloran's (1996) and Martimort's (1996) interprincipal competition models, Tirole's (1994) compartementalization of principals approach.

benefits from slashing and burning versus zero burning mechanical land clearing. Also recall from our model assumptions that slashing and burning is more profitable, $b_b > b_0$, the Center prefers zero burning $(b_0 - c_a) > b_b - h^c$ over slashing and burning and the Local Group prefers slashing and burning $b_b - h^l > b_0$.

The agent's i.e. the farmers' total compensation from the two principals amounts to

$$\mathbf{w} \equiv \mathbf{w}^c + \mathbf{w}^l = \begin{pmatrix} w_0^c \\ w_b^c \end{pmatrix} + \begin{pmatrix} w_0^l \\ w_b^l \end{pmatrix}. \tag{17}$$

Note that we now split the familiar compensations from the central government w^c and the Local Group w^l into their components, depending on the two possible outcomes: $\{w_0^c, w_b^c\}$ and $\{w_0^l, w_b^l\}$. Clearly, we anticipate that the central government offer more for zero burning than for slash and burn, $w_0^c > w_b^c$, and the Local Group prefers slash and burn, $w_b^l > w_0^l$. Interestingly, this model now allows for negative compensations to be paid by discuss below the possibility of the central government penalizing or levying slashing and burning, $w_b^c < 0$ and, on the other hand, the local group offering small compensation for mechanical land clearing without burning, $w_0^l \longrightarrow 0$.[20] We now turn to the outcome vector.

The compensations paid to the farmers induce the farmers' relative efforts, which in turn drive the outcome vector $\mathbf{x}$

$$\mathbf{x} \equiv \begin{pmatrix} x_0 \\ x_b \end{pmatrix} = \begin{pmatrix} t_0 \\ t_b \end{pmatrix} + \begin{pmatrix} \varepsilon_0 \\ \varepsilon_b \end{pmatrix}, \tag{18}$$

which describes the fraction of relevant forest and peatlands cleared using zero burning, mechanical methods versus slash and burn methods. Here $\{x_0 \geq 0, x_b \geq 0\}$ and $x_0 + x_b = 1$. It contains a normally distributed random error vector ε that the farmers' cannot control, whose mean are 0 and diagonal variance matrix is $\mathbf{\Psi}$. The farmers' i.e. agent's efforts independently relate to each of zero burning land clearing versus slash and burn, thus the cost of effort matrix C is positive definite and assumed to be modular,

$$\mathbf{C} \equiv \begin{pmatrix} c_0 & 0 \\ 0 & c_b \end{pmatrix}. \tag{19}$$

The farmers' efforts $\{t_0 \geq 0, t_b \geq 0\}$ can also be assumed to sum-up to one, $t_0 + t_b = 1$, without loss of generality. This reflects the fact that the average farmer has finite resources and time to engage in zero burning land clearing respectively slash and burn in parts of the relevant forest and peatland acreage. Alternatively one could interpret relative compensation and induced effort levels incentivizing one part of the group of farmers to choose slashing and burning, while the remaining

[20] We shall return to the negative compensation case later.

farmers may instead be motivated to opt for mechanical land clearing without burning. Tying back to our previous notation, for the farmers' cost of efforts e_0 and e_b we define

$$e \equiv \frac{1}{2}\begin{pmatrix} t_0 & t_b \end{pmatrix}\begin{pmatrix} c_0 & 0 \\ 0 & c_b \end{pmatrix}\begin{pmatrix} t_0 \\ t_b \end{pmatrix}. \tag{20}$$

The farmers' utility can now be expressed as

$$u(z) = -\exp\left\{-r\left[w - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}\right]\right\}, \tag{21}$$

which corresponds the farmers' utility's income equivalent $z = w - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}$ and assume constant risk aversion of the farmers. The principals' net payoffs become

$$E[\mathbf{b}'\mathbf{x}] - w = \mathbf{b}'\mathbf{t} - w \geq 0, \tag{22}$$

which must be positive to ensure their participation.

3.4.1 Fully Observable Efforts and Benevolent, Unified Principals

We start with the idealized scenario where all farmers' efforts $\mathbf{t}$ and outcomes $\mathbf{x}$ are observable and the interests of the central government and the Local Group are aligned. Here we consider a hypothetical scenario where both the Center and the Local Group are benevolent and pursue the best interest of the country as a whole. The farmers' certainty-equivalent net income relates to the FB case discussed in section 2.1 above, where the central government negotiates with its Neighbours, while being able to align all domestic interests, central and local. We summarize the results as follows:

Proposition 5 *Suppose a complete information setup where both the Center and the Local Group are benevolent principals and observe the efforts of the agent i.e. farmers in engaging in either slashing and burning or in zero burning mechanical land clearing. The principals and farmers jointly maximize total surplus by summing up their net payoffs. Using the farmers' utility from (21) and the principals' net payoffs (22) we apply the first order condition (FOC),* $\partial/\partial_{t_1,t_2}\left[\mathbf{b}'\mathbf{t} - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}\right] = 0$ *and obtain*

$$\mathbf{t}^{FO} = \mathbf{C}^{-1}\mathbf{b}. \tag{23}$$

Farmers will be incentivized and compensated to exert more effort to engage in zero burning mechanical land clearing, as

$$\begin{pmatrix} t_0^{FO} \\ t_b^{FO} \end{pmatrix} = \begin{pmatrix} (2b_0 - c_a)/c_0 \\ \left(2b_b - h^c - h^l\right)/c_b \end{pmatrix}. \tag{24}$$

The resulting total surplus S^{FO} enjoyed by both principals and the agent is therefore

$$S^{FO} = \frac{1}{2}\left[\frac{(2b_0 - c_a)^2}{c_0} + \frac{\left(2b_b - h^c - h^l\right)^2}{c_b}\right] \tag{25}$$

The farmers' total compensation is bounded by

$$\frac{1}{2}\left[\frac{(2b_0 - c_a)^2}{c_0} + \frac{\left(2b_b - h^c - h^l\right)^2}{c_b}\right] \leq w \leq \left[\frac{(2b_0 - c_a)^2}{c_0} + \frac{\left(2b_b - h^c - h^l\right)^2}{c_b}\right]$$

Proof. See Appendix 2.1. ■

Several points should be noted here. First, consistent with our previous results, the higher the incremental benefits from slashing and burning $b_b - b_0$, the more farmers will exert effort to engage in slashing and burning. Second, this result holds regardless of whether the Local Group also compensates for zero burning or not. As long as the Local Group is benevolent, which is assumed in this case, they will let the central government compensate the farmers, while supporting the maximization of joint surplus for the country. Third, as discussed, engaging in mechanical land clearing requires that the farmers exert higher effort, compared to slashing and burning. Thus $c_0 > c_b$, which makes the slash and burn choice easier for the farmers, unless the central government offers much more generous compensation. Fourth, if the cost of effort to the farmers c_0 of zero burning mechanical land clearing was prohibitively high (say $c_0 \longrightarrow \infty$), the farmers may find it more difficult to avoid engaging in slash and burn, regardless of the total costs and damages h^c. Fifth, we observe that the central government does not have to compensate (negatively) for slashing and burning, while the Local Group does not have to compensate (negatively) the farmers for zero burning mechanical land clearing.

Note, however, that here we assume benevolent central and local governments. As a result, when the total damages and costs are too high and the total benefits of slashing and burning turns negative, say when $2b_b - h^c - h^l < 0$ and thus $t_b^{FO} \leq 0$: farmers do not engage in slashing and burning at all. The Local Group completely avoids or does not compensate slash and burn at all even if mechanical land clearing was very costly. The plantation companies will not benefit from slashing and burning, because the local government is effectively not captured by the local business elites colluding with the plantation companies. We shall discuss this further in the next subsection, where under moral hazard local businesses, bureaucrats and thus the local collusion group pursue their own interests and contest the central government.

3.4.2 Moral Hazard with Competing Principals

We concentrate on a moral hazard setup, where the farmers' efforts $\mathbf{t}$ are not observable by the principals. The Central and the Local Group can only observe the outcome vector $\mathbf{x}$, after farmers' have completed their choice of engagement. The principals offer linear compensation contracts to the farmers, $\alpha^{j'}\mathbf{x} + \beta^j$ for $j = \{c, l\}$, aggregating to

$$w = \alpha'\mathbf{x} + \beta$$

based on the observed outcomes.

The farmers' expected utility from making effort $\mathbf{t}$ is now $u(z) = -\exp\left\{-r\left[\alpha'\mathbf{t} + \beta - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}\right]\right\}$. Following Billingsley's (1995) moment generating function for the normally distributed random error term of the farmers' efforts ε, results in the certainty-equivalent income of the farmers,[21]

$$z = \alpha'\mathbf{t} + \beta - \frac{1}{2}r\alpha'\mathbf{\Psi}\alpha - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}. \tag{26}$$

The resulting first order condition yields the optimal effort vector,

$$\mathbf{t}^{MH} = \mathbf{C}^{-1}\alpha. \tag{27}$$

Combining (26) and (27) yields a more useful expression for the farmers' certainty-equivalent income

$$z = \frac{1}{2}\alpha'\mathbf{C}^{-1}\alpha + \beta - \frac{1}{2}r\alpha'\mathbf{\Psi}\alpha. \tag{28}$$

Before continuing, it is now important to note that each of the two principals maximizes its expected surplus from bilaterally contracting with the agent. Each principal thus ignores the fact that its surplus is indirectly affected by the efforts the farmers exert as a result of receiving compensation from the other principal. Following a few mathematical steps which are laid out in detail in Appendix 2, we obtain each principal's surplus from their *own* respective contractual relationships with the farmers,

$$E\left[\mathbf{b}^{c'}\mathbf{x}\right] - \alpha^{c'}\mathbf{x} - \beta^c = \left(\mathbf{b}^c - \alpha^c\right)'\mathbf{C}^{-1}\alpha^c - \alpha^c\mathbf{C}^{-1}\alpha^l - \beta^c \tag{29}$$

and

$$E\left[\mathbf{b}^{l'}\mathbf{x}\right] - \alpha^{l'}\mathbf{x} - \beta^l = \left(\mathbf{b}^l - \alpha^l\right)'\mathbf{C}^{-1}\alpha^l - \alpha^l\mathbf{C}^{-1}\alpha^c - \beta^l. \tag{30}$$

Now each principal maximizes its own joint surplus with the farmers. Summing up (29) respectively (30) with the farmers' (28) and taking the first order condition with regard to α^c respectively α^l yields the principals' respective best response vector

$$\mathbf{b} = (I + 2r\mathbf{C}\mathbf{\Psi})\,\alpha, \tag{31}$$

[21] We follow Dixit's (1996) approach.

which comprises the Center's best response $\mathbf{b}^c = \alpha^c + r\mathbf{C}\mathbf{\Psi}\alpha$ and the Local Group's $\mathbf{b}^l = \alpha^l + r\mathbf{C}\mathbf{\Psi}\alpha$. Since r, $\mathbf{C}$ and $\mathbf{\Psi}$ are all positive we find that $\alpha < \mathbf{b}$ applies and thus the effort level under moral hazard is lower than under the fully observable case above, $\mathbf{t}^{MH} = \mathbf{C}^{-1}\alpha < \mathbf{C}^{-1}\mathbf{b} = \mathbf{t}^{FO}$.

We thus observe:

Proposition 6 *Assume a moral hazard case and a contest between the Center and the Local Group in persuading risk averse local farmers to engage in either zero burning mechanical land clearing or slashing and burning, or in splitting parts of their efforts in both activities. Each principal maximizes its own joint surplus with the farmers. The farmers maximize their certainty-equivalent income by applying the FOC on (26),* $\partial/\partial_{t_1,t_2}\left[\alpha'\mathbf{t} + \beta - \frac{1}{2}r\alpha'\mathbf{\Psi}\alpha - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}\right] = 0$*, resulting in the farmers' optimal effort level*

$$\mathbf{t}^{MH} = \mathbf{C}^{-1}\alpha < \mathbf{C}^{-1}\mathbf{b} = \mathbf{t}^{FO}, \tag{32}$$

which is lower than in the fully observable efforts case (see Appendix 2.1). The resulting farmers' effort vector can be shown to be

$$\begin{pmatrix} t_0^{MH} \\ t_b^{MH} \end{pmatrix} = \begin{pmatrix} (2b_0 - c_a)/(c_0 + 2r\psi_0 c_0^2) \\ \left(2b_b - h^c - h^l\right)/(c_b + 2r\psi_b c_b^2) \end{pmatrix}. \tag{33}$$

The total combined surplus of the Center, the Local Group and the farmers sums-up to

$$S^{MH} = \frac{1}{2}\left[\frac{(2b_0 - c_a)^2(1 + 4r\psi_0 c_0)}{c_0(1 + 2r\psi_0 c_0)^2} + \frac{\left(2b_b - h^c - h^l\right)^2(1 + 4r\psi_b c_b)}{c_b(1 + 2r\psi_b c_b)^2}\right], \tag{34}$$

which is lower than in the fully observable, benevolent and cooperative principals case S^{FO}*. The linear compensation offered to the farmers exhibit distinct coefficients* α^c *for the Center*

$$\alpha^c = \begin{pmatrix} (b_0 - c_a)/(1 + 2r\psi_0 c_0) > 0 \\ (b_b - h^c)/(1 + 2r\psi_b c_b) < 0 \end{pmatrix}.$$

and respectively α^l *for the Local Group*

$$\alpha^l = \begin{pmatrix} b_0/(1 + 2r\psi_0 c_0) \\ \left(b_b - h^l\right)/(1 + 2r\psi_b c_b) \end{pmatrix},$$

Proof. See Appendix 2.2 and discussion below. ■

Compare this result to the fully observable case above. When the farmers are risk averse, their incentives to engage in both tasks is lower-powered due to the added terms in the denominators, $2r\psi_0 c_0^2$ respectively $2r\psi_0 c_b^2$. We observe that the effort to engage in slashing and burning might actually be negative.

In addition, the added fractions $(1+4r\psi_0 c_0)/(1+2r\psi_0 c_0)^2 < 1$ respectively

$(1+4r\psi_b c_b)/(1+2r\psi_b c_b)^2 < 1$ lower total surplus, because the farmers' incentives are weakened. Under moral hazard the two principals' compensation schemes give the farmers less than the marginal contribution of their efforts for each of the two tasks. Thus the total combined surplus under moral hazard conditions and competing principals is lower than under full observation and benevolent, cooperating principals. Lower powered efforts result in smaller total surplus.

Note however, when either the risk aversion of the farmers is zero, $r = 0$, or if there is no random error term and the farmers always achieve the outcomes based on the efforts they exert with 100% certainty $\psi_0 = \psi_b = 0$, then the effort levels and total combined surplus under moral hazard still equal those of the fully observable, benevolent and cooperative principals, $\mathbf{t}^{MH} = \mathbf{t}^{FO}$ and $S^{MH} = S^{FO}$. By contrast, if the risk aversion of the farmers or the uncertainty of the outcome of their efforts is extremely high, e.g. $r \longrightarrow \infty$ and or ψ_0 and ψ_b approach infinity, the farmers exert no effort all in either tasks.

Interesting is the fact that, as long as the Center compensates the farmers with a positive income, $w^c > 0$, it can choose to negatively compensate the farmers for engaging in slashing and burning. This it could do by introducing stiff penalties and levying fines for farmers that engage in slashing and burning. Here the Center's compensation vector looks like

$$\mathbf{w}^c = \begin{pmatrix} w_0^c > 0 \\ w_b^c < 0 \end{pmatrix}.$$

As long as the Center offers farmers a positive aggregate compensation $w^c = w_0^c + w_b^c > 0$, it can still induce positive efforts from the farmers to engage more in zero burning mechanical land clearing. This can be shown using the linear compensation $\mathbf{w}^c = \alpha^{c'}\mathbf{x} + \beta^c$. We know from (27) and (33) that

$$\alpha^c = \begin{pmatrix} (b_0 - c_a)/(1+2r\psi_0 c_0) \\ (b_b - h^c)/(1+2r\psi_b c_b) \end{pmatrix}.$$

Since the Center suffers significant costs and damages from slashing and burning, $b_b - h^c < 0$, it penalizes and fines the farmers for any slashing and burning outcome, $\alpha_b^c < 0$. However, the overall compensation that the Center promises the farmers must still be positive, even if the term $2b_b - h^c - h^l < 0$ in (33) is negative and the farmers' effort level to engage in slashing and burning is negative. This is where the fixed positive compensation β^c, which is independent of the outcomes, is offered.

Lastly, depending on the Local Group's compensation,

$$\mathbf{w}^l = \begin{pmatrix} w_0^l \geq 0 \\ w_b^l > 0 \end{pmatrix},$$

the farmers will then exert the optimal level of effort by maximizing their certainty-equivalent income based on their combined total compensation from both principals. Thus the Local Group may choose not to incentivize the farmers in the case of mechanical land clearing. The Local Group can do this *ex ante*, by deterring or even harassing farmers who may not wish to engage in slashing and burning (thereby increasing c_0) or *ex post*, by *disincentivizing* farmers who engage in mechanical land clearing and thus refuse to slash and burn. Nevertheless considering the linear compensation $\mathbf{w}^l = \alpha^{l'}\mathbf{x} + \beta^l$ which includes the outcome-dependent coefficient

$$\alpha^l = \begin{pmatrix} b_0/\left(1 + 2r\psi_0 c_0\right) \\ \left(b_b - h^l\right)/\left(1 + 2r\psi_b c_b\right) \end{pmatrix},$$

we see that the Local Group also benefits positively from mechanical land clearing, albeit not as much as from slashing and burning. Thus its coefficient $\alpha_0^l > 0$ must be positive and the Local Group will not offer negative compensation to any farmers. At most the Local Group will not compensate farmers who refuse to engage in slashing and burning. Clearly, we observe that the effectiveness of each principal's compensation in inducing the right mix of efforts from the farmers, depends also on the compensation level offered by the competing principal.

3.5 Comparison of the Competing Principals and Multitask Multi-principal Models

Our principal competition model shows that to win the contest against the Local Group in incentivizing farmers to engage in zero burning mechanical land, the Center must offer high compensation to the farmers and invest in enforcement and abatement policies. We find that the required compensation increases, the more highly profitable slash and burn land clearing becomes for the relevant companies, which are part of the local colluding group i.e. principals. In extreme cases, the involved companies may even negotiate for partial or full profit reimbursements. In theory, higher incremental benefits and profits of slashing and burning increase the amount of such profit reimbursements and make it more difficult for the Center to reimburse profits in full. Nevertheless, we do not believe that profit reimbursement is a likely scenario, unless the Center is captured by the Local Group.

We now compare the results we derive using our model of competing principals with our observations from applying the dual-task dual-principal model. First, the dual-task dual-principal model allows for the possibility of partial outcomes, where both Center and Local Group, subject to their respective participation constraints in (22), compensate the farmers to split their efforts into both activities. The outcome is such that a part of the forest and peatland acreage is cleared

using purely mechanical land clearing, while the remaining acreage is slashed and burned. By contrast, our principals competition model assumes a binary decision by the farmers, each pertaining to the entire relevant forest and peatland acreage.

Second, the dual-task dual-principal model presupposes a sequential decision making process by the farmers, where the farmers compare the two principals' contract i.e. compensation offers, choose one or a combination of both, and then implement and engage. Under moral hazard assumptions the principals i.e. Center respectively Local Group will subsequently pay the compensation after observing the respective outcomes. While this doesn't prevent the principals from paying the farmers' compensation on a daily basis or partially upfront, it is rational to expect that the principals will only pay the full or remaining compensation once all the work has been completed and the results observed. Here the farmers are vulnerable to potential manipulation or over-promises by the principals.

Third, it should be noted that one important assumption we made in applying the dual-task dual-principal model pertains to the farmers' outside employment option we reviewed in section 3.1.4, which we ignore in this analysis. Were we to include such non-land clearing outside options in a two-principal three-task model, the principals would not compensate the farmers directly for the outside option but will gain additional income tax benefits from the farmers' outside employment. Each of the principals' benefits vectors will have three elements. The farmers' utility and income will have a third non-zero element representing their outside income. Concurrently, the farmers' effort vector will have three elements and the cost of effort matrix will have 2x3 = 6 elements. Additionally, the dual-task dual-principal model could be expanded further to include a third principal, the neighbouring government, resulting in a three-principal three-task model.

Fourth, in our model of competing principals we provide the possibility of the punishment of the violating Local Group and its members, but not the farmers directly. By contrast, our dual-task dual-principal model allows for the Center to negatively compensate and thus directly penalize and fine farmers i.e. the common agent for engaging in slashing and burning. Concurrently, the Local Group could also penalize legal, mechanical land clearing, be it by forceful coercion or outright intimidation. Nevertheless, such punishment and deterrent of farmers can be modelled into both our frameworks: In the competing principals' model by increasing the efforts of slashing and burning, e_b, respectively of mechanical land clearing, e_0. and in the dual-task dual-principal model by increasing the cost of effort of slashing and burning, c_b, respectively of mechanical land clearing, c_0. Indeed both approaches allow for increased deterrence and possible punishment through more rigorous enforcement and and thus (the threat of) punishment.

4 Policy Implications

In the transboundary fire and haze game of chicken the Center could credibly signal its reluctance to fund and invest in the enforcement and abatement program. This forces neighbouring governments to try to fund and invest in enforcement and abatement, either unilaterally or jointly with the Indonesian central government. By contrast, when unilateral efforts by the Neighbours are less effective or efficient, the Neighbours should try to convince the Indonesian central government to unilaterally or jointly fund and invest in enforcement and abatement.

We expand the range of policy strategies in two directions. On the one hand, we derive policy solutions to the local capture and common agency problems. Breaking up or weakening the Local Group enhances the Center's authority and strengthens its bargaining stance vis-a-vis its Neighbours is one strategy. Incentivizing local farmers and residents to engage in alternative employment options is another. One the other hand, given the high costs and damages of fire and haze and seeing the Center in an active contest with the Local Group, the Neighbour knows that the Center cannot credibly threaten to not invest in enforcement and abatement. Thus the Center could or must collaborate with its Neighbour as well as multilateral agencies, other governments and non-governmental institutions. Moreover, the Neighbour may offer technical and funding resources and/or punish violating companies who have financial and other business activities in the neighbouring country.

Following the model observations discussed above, all policy strategies should focus on increasing the indifference point Φ. This involves increasing the effective costs and damages to the Local Group, h^l, reducing the cost of abatement and enforcement c_a and increasing punishment and penalties for slashing and burning θ, increasing the effort costs of slashing and burning, e_b and c_b respectively decreasing effort costs of legal mechanical land clearing, e_0 and c_0, all the while reducing information costs through technology (again, reducing c_a) and by strengthening the relevant institutions. Moreover, ways need to be found to decrease the Local Group's effective benefits from burning, $\Delta b \equiv b_b - b_0$.

4.1 Game of Chicken with Neighbour

An optimal solution to the combined game of chicken and common agency problem is for the Center and its Neighbours to jointly fund and invest in enforcement and abatement. This relaxes the Center's budget constraint, improves their funding, managerial and technical resources and increases its ability to offer higher compensation to the farmers, to not slash and burn. Besides,

teaming up helps solve any possible ineffectiveness of the neighbour's unilateral enforcement and abatement programs. Since the Center must win the contest against the Local Group in persuading and compensating farmers to not slash and burn, it must further try to expand its funding sources to relax its budget constraint. This could be approached through participation in multilateral environmental bargaining forums, seeking aid from multilateral agencies and donors like the World Bank, ADB, supportive governments and non-governmental institutions worldwide. Beyond the sharing of enforcement and abatement costs and pooling of monitoring, financial and negotiation power, neighbouring governments could help punish violating companies that maintain business or financing activities in their jurisdictions.

Center and neighbouring government could also jointly increase the cost of effort to farmers of engaging in slashing and burning, including through stricter monitoring and enforcement. The collaboration can also be expanded to include technological support from the neighbour, like for example satellite imaging methods, digital and data analytics skills. To enhance the collection of accurate fire data, national and local regulatory institutions and non-governmental organizations (NGOs) should collaborate with local bureaucrats in monitoring the behaviour of plantation companies. National regulators and NGOs should concurrently use satellite imaging and other surveillance technologies to collect accurate data independently from the local bureaucrats and their local appointees. This helps mitigate the information asymmetry problem, which in turn allows the Center to more accurately identify and punish the violating companies, farmers and bureaucrats and to better reward desirable behaviour.

4.2 Local Farmers' Common Agency Problem

Several of the above mentioned policy options help mitigate the local multiprincipal and common agency problems. Relaxing the Center's budget constraint by cooperating with Neighbours and other institutions allows the Center to offer higher compensation to the farmers, versus the Local Group. Strict enforcement and steep fines and penalties for violating the no burning laws and regulations and increasing the farmers' potential outside income all make it harder for the Local Group to influence the farmers. Given the high cost of compensating farmers and engaging in a mutually costly contest with the Local Group, it can be more efficient for the Center to strictly prohibit slashing and burning.

Should its budget limitations not suffice to invest in full enforcement and abatement programs, the Center could choose to focus on certain forest and peatland areas. Any partial solutions are better than none at all. The key is to counter and solve the information disadvantage in terms of

identifying farmers and residents as well as acreage that are more vulnerable to slash and burn. First, land ownership and mapping data must be reevaluated and reconfirmed. Second, some parts of the local populace might be, due to their prior employment history, social conditions or income levels, more prone to getting persuaded by the Local Group. Third, some portions of the regional forest and peatland acreage might be either more lucrative for slashing and burning or may result in higher direct costs and damages to humans, materials and the environment. The Center's enforcement and abatement efforts and investments could be focused more intensively on these more vulnerable segments of the populace respectively acreage.

Importantly, the Indonesian and neighbouring government should collaborate in breaking the collusion among local bureaucrats, business elites and the relevant companies. Weakening the Local Group will ensure the Center sufficient decision making authority and the power to implement effective enforcement and abatement policies. Increasing empowerment of local and central anti-corruption agencies, non-governmental organizations as well as the monitoring and enforcement -partially by the local citizens themselves- of the local elections can all contribute to increasing transparency in local politics and to reducing the possibilities and incentives for local collusion.

Transparency of local business activities and dealings can also be improved. Improved organization and legal clarity about land acreage ownership and usage facilitates the monitoring of local and regional forest and peatland acreage. The use of modern satellite, sensor and surveillance technologies to monitor and continuously update databases of local forest and land clearing activity, of local bureaucrats and business activity. The involvement of local and national media and non-governmental organizations can be helpful.

Another approach is to incentivize the local business elites and companies not to engage in slash and burn. While it is theoretically possible, or occasionally necessary, to offer them partial or full reimbursement of the incremental profit of slash and burn, this is very expensive.[22] It is more cost-effective to incentivize local bureaucrats and local businesses by supporting and subsidizing them with important, visible and relevant infrastructure projects. This improves the bureaucrats' standing in the local communities and provide the businesses and companies with infrastructure that enhances their business. Working outside its immediate fire and haze-related budget constraint, the Center thus incentivizes local bureaucrats to engage in programs that create positive externalities to the local economy and populace. This makes an involvement in slash and burn activities less attractive, while compensating the local bureaucrats and businesses with both monetary and non-monetary benefits.

[22] Recall our discussion on abatement and enforcement costs and Table 1 above.

With regard to the effort costs involved with purely mechanical land clearing works, it is helpful if the government can help farmers with enabling equipment and training. Farmers and residents can be offered incentives and transfers to seek alternative employment opportunities. This strategy can be reinforced by the Center offering schooling, education and retraining to local farmers and residents. Sound industrial policy, local economic development and entrepreneurial education programs will expand new employment and business opportunities for the local farmers and residents. The Center could offer farmers non-monetary compensation such as local awards and contests, conditional health care services for families or in-kind farming opportunities to farmers. Such benefits should be offered conditional on the farmers not engaging in slash and burn activities. Public information sessions about the health and environmental damages and costs of forest and peatland burning and the associated haze should be offered. Farmers can be deterred from slashing and burning with the threat of strict monitoring, severe penalties and by increasing their effort levels for slashing and burning. In the worst cases government could also revert to direct penalties and punishments of violating farmers.

Additionally, the Center should try to induce information asymmetry and, if possible, competition among the members of the Local Group. Such a divide and conquer strategy could compartementalize responsibilities among the various local government departments and bureaucrats. Creating information barriers and sowing distrust among the local bureaucrats, companies and the brokering business elites may weaken the local collusion and increase their intra-group transaction costs.

Lastly, since a significant portion of (reported) corporate income taxes are collected by the Center and returned to the local government, the Center could in principle reduce the effective benefit of slashing and burning if it can identify the violating companies. This will tighten the Local Group's budget constraint and make it more likely for the Center to offer a higher compensation and avoid slashing and burning.

5 Summary and Limitations

The local capture and common agency problem observed in conjunction with Indonesia's transboundary haze game of chicken are examined. Both the competing principals and dual-task dual-principal models are utilized to derive solution strategies for Indonesia and its Neighbours. We find that the central government can persuade farmers and prevent burning when the incremental benefits from slashing and burning are lower, the total direct and indirect costs and damages of fire and haze are higher and the required enforcement and abatement costs are not too high.

Neighbouring governments can help mitigate the central government's budget constraint and deter or punish violating multinational companies. The central government could also introduce a combination of positive incentives and negative punishments to prevent slashing and burning in at least part of the forest and peatlands.

Our results inform on several policy strategies. The optimal solution is for the central government and its neighbours to jointly invest in enforcement and abatement, reduce information and monitoring costs and strictly punish violating companies. Farmers can be offered alternative employment and training as part of broader, more sustainable industrialization programs. Local bureaucrats and companies can be encouraged to engage in alternative welfare-enhancing infrastructure projects. Finally, the central government should find ways to break the local collusion.

Our models assume a unified local collusion group. No partial disagreements are considered, for example where the local government may not completely ignore the indirect costs and damages of fire and haze. While the dual-task dual-principal model allows for moral hazard, the competing principals setup does not formally model incomplete information.

Our analysis can be expanded in several directions. First, we could introduce asymmetric information and multi-period, repeated plays into the game of chicken and the competing principals models. Second, the dual-task dual-principal model can be expanded to include farmers' outside options i.e. employers, neighbouring governments, several local principals including local government, companies. The resulting model will be a kind of two-task multiple-principal common agency model. Third, the static one-stage models can be expanded into a repeat game setup that captures repeated -sequential or simultaneous- moves both in the transboundary Center-Neighbour game and in the Center-Local Group common agent contest. Fourth, empirical studies can be conducted on the impact of regional and local variables such as growth and local incomes, stage of economic development and industrialization, occurrence of petroleum and mining resources and revenues, government budgets, economic governance index (EGI) and other socio-economic indicators on the proportions of legal zero burning versus illegal slash and burn activities. Past studies on related themes include Burgess et al. (2012), Cisneros et al. (2021), Bandiera and Levy (2011), and Rusli and Vermeulen (2019). Fifth, political economy studies on the roles of multilateral agencies and other governmental and non-governmental agencies in motivating, helping or punishing governments like Indonesia and, in particular, in helping central governments and supranational institutions (like the European Commission) in politically decentralized countries (common markets) will be of increasing importance and research interest.

References

Adriani, M. "Methodology in Estimating Damage and Losses of Indonesia Forest Fires in 2015." Jakarta, Indonesia: World Bank (2016).

Bandiera, O., and G. Levy. "Diversity and the Power of the Elites in Democratic Societies: Evidence from Indonesia." *Journal of Public Economics*, Vol. 95:11-12 (2011).

Bernheim, B. D., and M. Whinston. "Common-Agency." *Econometrics*, Vol. 54:4 (1986), pp. 911-930.

Billingsley, P. "Probability and Measure". New York, NY: Wiley Series in Probability and Mathematical Statistics (1995).

Burgess, R., M. Hansen, B. Olken, P. Potapov, and S. Sieber. "The Political Economy of Deforestation in the Tropics." *The Quarterly Journal of Economics*, Vol. 127:4 (2012).

Calvo, E., and S. Rubio. "Dynamic Models of International Environmental Agreements: A Differential Game Approach." *International Review of Environmental and Resource Economics*, Vol. 6:4 (2013), pp. 289-339.

Chander, P., and H. Tulkens. "The Kyoto Protocol, the Copenhagen Accord, the Cancun Agreements, and beyond: An economic and game theoretical exploration and interpretation". *CORE Discussion Paper 51* (2011).

Cisneros, E., K. Kis-Katos, and N. Nuryartono. "Palm Oil and the Politics of Deforestation in Indonesia." *Journal of Environmental Economics and Management*, Vol. 108 (2021).

Dixit, A. "The Making of Economic Policy: A Transaction-Cost Politics Perspective." Cambridge, MA: The MIT Press (1996).

Edwards, R.B., W.P. Falcon, G. Hadiwidjaja, R.L. Naylor, S. Sumarto. "Fight Fire with Finance: A Randomized Field Experiment to Curtail Land-Clearing Fire in Indonesia." *TNP2K Working Paper* 55-e (2020a).

Edwards, R.B., R.L. Naylor, M.M. Higgins, and W.P. Falcon. "Causes of Indonesia's Forest Fires." *World Development,* Vol. 127 (2020b).

Edwards, S.A., and F. Heiduk. "Hazy Days: Forest Fires and the Politics of Environmental Security in Indonesia." *Journal of Current SE Asian Affairs*, Vol. 34:3 (2015), pp. 65-94.

Ekadinata, S., M. van Noordwijk, S. Budidarsono, and S. Dewi. "Hot Spots in Riau, Haze in Singapore: The June 2013 Event Analyzed." *ASB Policy Brief*, No. 33 (2013), ASB Partnership for the Tropical Forest Margins, Nairobi.

Epstein, D., and S. O'Halloran. "A Theory of Strategic Oversight: Congress, Lobbyists, and the Bureaucracy." *Journal of Law, Economics and Organization*, Vol. 11 (1996), pp. 227-255.

Eyckmans, J., and M. Finus. "Coalition Formation in a Global Warming Game: How the Design of Protocols Affects the Success of Environmental Treaty-Making". *Natural Resource Modelling* (2008).

Finus, M. *Game Theory and International Environmental Cooperation.* Edward Elgar Publishing Ltd. (2001).

Fitrani, Fitria, Bert Hofman, and Kai Kaiser. "Unity in Diversity? The Creation of New Local Governments in a Decentralizing Indonesia." *Bulletin of Indonesian Economic Studies*, Vol. 41:1 (2005), pp. 57-79.

Ford, J. Fitz G., and Bambang Brodjonegoro. "Inter-Governmental Fiscal Relations and State Building: The Case of Indonesia", in *Fiscal Fragmentation in Decentralized Countries: Subsidiarity, Solidarity and Asymmetry*, editors Bird, Richard M. and Robert D. Ebels (2004), pp. 320-62.

Glauber, A.J., and I. Gunawan. "The Cost of Fire: An Economic Analysis of Indonesia's 2015 Fire Crisis." Jakarta, Indonesia: World Bank (2016).

Gouyon, A., and D. Simorangkir. *The Economics of Fire Use in Agriculture and Forestry: A Preliminary Review for Indonesia.* WWF (2002), Gland, Switzerland.

Grossman, G. M., and E. Helpman. "Protection for Sale." *American Economic Review*, Vol. 84:4 (1994), pp. 833-850.

Holmstrom, B., and P. R. Milgrom. "Multitask Principal-Agent Analysis: Incentive Contracts, Asset Ownership, and Job Design." *Journal of Law, Economics and Organization*, Vol. 7 (1991), pp. 24-51.

Martimort, D. "Exclusive Dealing, Common-Agency, and Multiprincipals Incentive Theory." *The RAND Journal of Economics*, Vol. 27:1 (1996), pp. 1-31.

Martimort, D., and L. Stole. "The Revelation and Delegation Principles in Common-Agency Games." *Econometrica*, Vol. 70:4 (2002), pp. 1659-1673

Nguitragool, P. "Negotiating the Haze Treaty: Rationality and Institutions in the Negotiations for the ASEAN Agreement on Transboundary Haze Pollution 2002." *Asian Survey*, Vol. 5:2 (2011), pp. 356-378.

Purnomo, H., and B. Shantiko. "The Political Economy of Fire and Haze: Root Causes." *Discussion Forum: Long-term Solutions to Fires in Indonesia: Multi-Stakeholder Efforts and the Role of the Private Sector, Global Landscape Forum* (2015), Paris.

Purnomo, H., B. Shantiko, S. Sitorus, H. Gunawan, R. Achdiawan, H. Kartodihardjo, and A. A. Dewayani. "Fire Economy and Actor Network of Forest and Land Fires in Indonesia." *Forest Policy and Economics*, Vol. 78 (2017), pp. 21-31.

Quah, Euston, with Tsiat Siong Tan. *Pollution Across Borders: Transboundary Fire, Smoke and Haze in SE Asia.* Nanyang Technological University (2018).

Rusli, R. D., "The Indonesian transboundary haze game: Countering free-riding and local capture", in *Pollution Across Borders: Transboundary Fire, Smoke and Haze in SE Asia*, Editor Euston Quah with Tsiat Siong Tan, Nanyang Technological University (2018).

Rusli, R. D., and Wessel N. Vermeulen. "Subnational Government Budgets and Resource Revenues in Indonesia: Indications of Resource Blessings?" *Oxford Centre for the Analysis of Resource Rich Economies (OxCarre)*, Research Paper 222 (2019).

Selten, R. "The Chain-Store Paradox." *Theory and Decision*, Vol. 9:2 (1978), pp. 127-159.

Simorangkir, D. "Fire use: is it really the cheaper land preparation method for large-scale plantations?" *Mitigation and Adaptation Strategies for Global Change*, Vol. 12 (2007), pp. 147-164.

Tacconi, L. "Fires in Indonesia: Causes, Costs and Policy Implications." *CIFOR Occasional Paper*, No. 38 (2003).

Tacconi, L., P.F. Moore, and D. Kaimowitz. "Fires in Tropical Forests - What is Really the Problem? Lessons from Indonesia." *Mitigation and Adaptation Strategies for Global Change*, Vol. 12:1 (2007), pp. 55-66.

Tacconi, L. "Preventing Fires and Haze in Southeast Asia." *Nature Climate Change*, Vol. 6 (2016), pp. 640-643.

Tan, A. K.-J. "The Haze Crisis in Southeast Asia: Assessing Singapore's Transboundary Haze Pollution Act 2015." *NUS Law Working Paper 2015/002*, Singapore (2015).

Tirole, Jean. "The Internal Organization of Government." Oxford Economic Papers, Vol. 46:1 (1994), pp. 1-29.

Appendix 1: Extensions to the Transboundary Game of Chicken

A few points are noteworthy with regard to the game of chicken between the Indonesian central government and its neighbours.[23] First, we examine the assumption of comparable effectiveness of enforcement and abatement efforts. The neighbouring government's investment in the full enforcement and abatement costs may not be effective in completely eradicating slash and burn practices in

[23]See Rusli (2018) for a more detailed analysis of the bargaining results, solution and policy strategies following relaxation of the FB assumptions of the game of chicken.

Indonesia. Possible reasons may be resistance and lack of cooperation from local governments and business elites in the relevant regions, inadequate data on concession boundaries and fire locations or insufficient knowledge of the local bureaucrats' and business elites' strategies and incentives. As a result, residual damages and losses $h^{totr} = h^{cr} + h^{nr}$ may persist even after the neighbouring government has spent the full amount c. This would lead to a different payoff structure of the haze game. In particular, the payoff of the first Nash equilibrium {Not-invest, Invest} may shift to $[b_0^c - h^{cr}, -c - h^{nr}]$. In the extreme case the Indonesian government would now be prepared to co-invest if the residual damages and losses are high enough and it does not have to share too much of the enforcement and abatement costs. Thus whenever h^{cr} is high enough such that

$$b_0^c - h^{cr} < b_0^c - (1-\gamma)\, c$$

is satisfied, Indonesia will co-invest, resulting in {Invest, Invest}.[24] As a consequence, investing in enforcement and abatement could become the dominant strategy for the Indonesian government, regardless of whether the neighbour cooperates and invests jointly or not at all. At the same time, knowing that the Indonesian central government will invest, the neighbouring government may at some point find it advantageous to free-ride and not invest at all. Indeed as soon as the residual damages and losses exceed the cost of enforcement and abatement, $h^{nr} + c \geq h^n$, the pure strategy of {Invest, Not-invest} is reached as a single Nash equilibrium solution, In other words, the neighbouring government may decide not to invest at all. Note that under the original assumption of effective enforcement and abatement by either government, the aggregate payoffs of the two Nash equilibria, and the cooperative outcome of joint investing, achieve the same at $b_0^c - c$. However, if the neighbouring government is less effective in enforcing zero burning policies in Indonesia, the resulting unique Nash equilibrium of {Invest, Not-invest} is the globally welfare-optimal solution. Policy prescriptions should then be identified to nudge the game into this equilibrium.

Second, the Indonesian government, whether due to bounded rationality or capture by the local collusive group, may not observe or consider the indirect environmental costs, productivity and industrial losses. From Table 1, say that the costs of fire and haze observed and considered by the government are limited to a subset h^{eff} of the direct damages and losses only, $h^{eff} < h^c < h^{tot}$. Especially when the cost of enforcement and abatement c is sufficiently high, the payoff structure could change, such that for the central Indonesian government {Not-invest,•} becomes the dominant strategy because $b_b^c - h^{eff} > b_0^c - c$ while, naturally, $b_0^c > b_0^c - (1-\gamma)\, c$. This in turn allows it to force the neighbouring government to invest in enforcement and abatement provided $c < h^n$; it is now costlier for the neighbouring government to leave the fire and haze unabated, than

[24] This inequality can be rewritten as $(1-\gamma) < \frac{h^{cr}}{c}$. The smaller h^{cr}, the less willing is Indonesia to (co-)invest.

to invest in the necessary measures. The new Nash equilibrium ends up at {Not-invest, Invest} and the Indonesian government now chooses to free-ride on its neighbour.

Note, however, that this only holds as long as the perceived/relevant direct health and damages costs perceived by the central government, which as mentioned above may be non-zero if the neighbouring government was not as effective in implementing the enforcement and abatement measures, are not too large such as to *violate* the inequality $b_0^c - h^{effr} > b_0^c - (1-\gamma)\,c$. Here we define h^{effr} as the subset of residual direct health and damages costs, following incomplete enforcement and abatement efforts led by the neighbouring government, to the Indonesian central government. If $b_0^c - h^{effr}$ does indeed fall below $b_0^c - (1-\gamma)\,c$ both governments would have to accept the benefits of cooperating and jointly investing in enforcement and abatement.

Third, note that until now we neglect the negative domestic and international reputational and political costs of the Indonesian government not proactively making efforts and investing in fire and haze enforcement and abatement. These costs are more difficult to quantify. Moreover, the abovementioned myopia and political pressure, combined with agency and capture problems, may force the government to ignore or underplay the reputational issues of not investing. At the very least, it will try to introduce measures that may give the appearance of it trying hard to mitigate the forest fires and incentivize the various parties to adhere to the zero burning laws and regulations.

Lastly, one more interesting extension to the above game of chicken is if it is repeated along multi-periods. Now assume, plausibly, that the Indonesian government makes the first "move" (of not investing) and the neighbour follows. In this case the payoffs are $[b_0^c, -c]$ when the neighbour invests i.e. {Not-invest, Invest} and respectively $[b_b^c - h^c, -h^n]$ when the neighbour also refrains from investing, {Not-invest, Not-Invest}. Clearly, it is rationale for the neighbour to invest whenever, as argued, $h^n > c$. Thus as long as the Indonesian central government upholds its reputation for neglecting to invest in enforcement and abatement, the Neighbour(s) are forced to invest.[25] This solution will remain the same however long the game of chicken is played. The opposite case of a sequential game of chicken starts with the Neighbour credibly signalling its intention not to invest in enforcement and abatement. The solution will then mirror the previous; in this case the Indonesian government must invest. Note, however, as discussed in section 3.3, under the local capture and common agency setup any attempt by the Indonesian central government to negotiate with farmers and against the local collusion group will result in the neighbour free riding, as the latter will not deem any signal of the central government not investing in enforce-

[25] Of course subject to the local political economy and efficiency limitations discussed above.

ment and abatement not credible. In summary, supposing sequential decisions by the Indonesian central government and its neighbours, a repeat game of chicken exhibits similar characteristics to Selten's (1978) chain store paradox. Until the game of chicken interacts with the local capture and common agency scenarios, which is an interesting question for future study.

Appendix 2: Multitask Multiprincipal Model

We make use of Dixit's (1996) multitask multiprincipal model.[26] Suppose that an agent controls m-dimensional effort and output vectors t and x. There are n risk-neutral principals who gain linear benefits b from the agent's output. The output vector

$$\mathbf{x} = \mathbf{t} + \varepsilon$$

contains a normally distributed random error ε that the agent cannot control, whose mean is 0 and diagonal variance matrix is $\mathbf{\Psi}$. The j-th principal's benefit is $\mathbf{b}^{j'}\mathbf{x}$ and the sum of all principals' benefits is $\mathbf{b} = \sum_{j=1}^{n} \mathbf{b}^j$. The principals offer their individual compensation to the agent z^j, collectively amounting to $z = \sum_{j=1}^{n} z^j$. The agent's utility function has constant risk-aversion,

$$u(z) = -\exp(-rz)$$

where z equals money income w minus the quadratic cost of effort, $\frac{1}{2}\mathbf{t'Ct}$, where $\mathbf{C}$ is the agent's cost of efforts matrix.

Applied to our central government versus Local Group setup with the farmers as the common agent, the principals' benefits become

$$\mathbf{b} = \mathbf{b}^c + \mathbf{b}^l = \begin{pmatrix} (b_0 - c_a) \\ b_b - h^c \end{pmatrix} + \begin{pmatrix} b_0 \\ b_b - h^l \end{pmatrix}. \tag{35}$$

Recall that $b_b > b_0$, the central government prefers $(b_0 - c_a) > 0$ over $b_b - h^c < 0$ and the Local Group prefers $b_b - h^l > 0$ over $b_0 > 0$.

The farmers' total compensation from the two principals amounts to

$$w \equiv w^c + w^l. \tag{36}$$

Compensations w^c and w^l can be positive or negative, based on the respective principals' preferences. The compensations paid to the farmers induce the farmers' effort vector $\mathbf{t}$ and in turn drive

[26] See the Appendix. Dixit (1996) combines the multitask agency models of Holmström and Milgrom (1990, 1991) and Bernheim and Winston's (1986) multiprincipal common agency model.

the outcome vector $\mathbf{x}$

$$\mathbf{x} \equiv \begin{pmatrix} x_0 \\ x_b \end{pmatrix} = \begin{pmatrix} t_0 \\ t_b \end{pmatrix} + \begin{pmatrix} \varepsilon_0 \\ \varepsilon_b \end{pmatrix}. \tag{37}$$

Here $\{x_0 \geq 0, x_b \geq 0\}$ and $x_0 + x_b = 1$. While the farmers' efforts independently relate to each of zero burning land clearing versus slash and burn, the cost of effort matrix $\mathbf{C}$ is positive definite and initially assumed to be modular

$$\mathbf{C} \equiv \begin{pmatrix} c_0 & 0 \\ 0 & c_b \end{pmatrix}.^{27}$$

The farmers' efforts $\{t_0 \geq 0, t_b \geq 0\}$ can also be assumed to sum-up to one, $t_0 + t_b = 1$. The farmers' cost of efforts e_0 and e_b is defined as

$$e \equiv \frac{1}{2} \begin{pmatrix} t_0 & t_b \end{pmatrix} \begin{pmatrix} c_0 & 0 \\ 0 & c_b \end{pmatrix} \begin{pmatrix} t_0 \\ t_b \end{pmatrix}. \tag{38}$$

The farmers' utility can now be expressed as $u(z) = -\exp\left\{-r\left[w - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}\right]\right\}$, which corresponds the farmers' utility's income equivalent

$$z = w - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t} \tag{39}$$

and the principals' net payoffs as

$$E\left[\mathbf{b}'\mathbf{x}\right] - w = \mathbf{b}'\mathbf{t} - w. \tag{40}$$

Appendix 2.1: Fully Observable, Benevolent and Unified Principals

We choose the effort vector $\mathbf{t}$ that maximizes the sum of the principals' benefits and the agent's equivalent income, i.e. the total surplus, (39) plus (40). This yields the optimal effort level

$$\mathbf{t}^{FO} = \mathbf{C}^{-1}\mathbf{b} = \begin{pmatrix} t_0^{FO} \\ t_b^{FO} \end{pmatrix} = \begin{pmatrix} (2b_0 - c_a)/c_0 \\ \left(2b_b - h^c - h^l\right)/c_b \end{pmatrix} \tag{41}$$

and the total combined surplus of the central government, the Local Group and the farmers amounts to

$$S^{FO} = \frac{1}{2}\left[\frac{(2b_0 - c_a)^2}{c_0} + \frac{\left(2b_b - h^c - h^l\right)^2}{c_b}\right]. \tag{42}$$

Since the farmers' participation constraint must be satisfied, the minimum combined compensation to the farmers must be at least $w = \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}$, which corresponds to $w_{\min} \geq \frac{1}{2}\left[(2b_0 - c_a)^2/c_0 + \left(2b_b - h^c - h^l\right)^2/c\right.$ On the other hand, the principals cannot offer a higher compensation than the total benefits they can enjoy, $w_{\max} \leq \left[(2b_0 - c_a)^2/c_0 + \left(2b_b - h^c - h^l\right)^2/c_b\right]$.

Appendix 2.2: Moral Hazard and Competing Principals

We now examine the moral hazard case of unobservable efforts of the farmers. The principals compete for the farmers' engagement and offer their respective compensations, each in accordance with their distinct preferred outcomes. We look for the Nash equilibrium of the principals' choices, i.e. primarily zero burning mechanical clearing for the Center and slash and burn for the Local Group. The principals' compensation to the farmers can be of a linear form, $w = \alpha'\mathbf{x} + \beta$, without loss of generality.[28] Clearly $w = w^c + w^l$ and comprises $w^c = \alpha^{c'}\mathbf{x} + \beta^c$ and $w^l = \alpha^{l'}\mathbf{x} + \beta^l$. On the one hand, we allow for the possibility that the Center *negatively* compensates the farmers for slashing and burning, in form of penalties and fines. On the other hand, the Local Group may compensate mechanical land clearing, presumably at a lower level compared to slashing and burning, or even negatively. The latter may relate to some kind of harassment or deterrent that the local business elites may threaten the farmers with.

The farmers' expected utility from making effort $\mathbf{t}$ is now $u(z) = -\exp\left\{-r\left[\alpha'\mathbf{t} + \beta - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}\right]\right\}$ which, following Billingsley's (1995) moment generating function for the normally distributed random error term of the farmers' efforts ε results in the certainty-equivalent income of the farmers,

$$z = \alpha'\mathbf{t} + \beta - \frac{1}{2}r\alpha'\mathbf{\Psi}\alpha - \frac{1}{2}\mathbf{t}'\mathbf{C}\mathbf{t}. \tag{43}$$

The resulting first order condition yields the optimal effort vector,

$$\mathbf{t}^{MH} = \mathbf{C}^{-1}\alpha. \tag{44}$$

Substituting into (43) we thus get the farmers' certainty-equivalent income $z = \frac{1}{2}\alpha'\mathbf{C}^{-1}\alpha + \beta - \frac{1}{2}r\alpha'\mathbf{\Psi}\alpha$, which can be rewritten as

$$= \frac{1}{2}\left(\alpha^c + \alpha^l\right)'\left(\mathbf{C}^{-1} - r\mathbf{\Psi}\right)\left(\alpha^c + \alpha^l\right) + \left(\beta^c + \beta^l\right). \tag{45}$$

Using (44) the Center's expected surplus can be calculated to yield

$$\mathbf{b}^{c'}\mathbf{t} - \alpha^{c'}\mathbf{t} - \beta^c = \left(\mathbf{b}^c - \alpha^c\right)'\mathbf{C}^{-1}\left(\alpha^c + \alpha^l\right) - \beta^c \tag{46}$$

and the Local Group's surplus of

$$\mathbf{b}^{l'}\mathbf{t} - \alpha^{l'}\mathbf{t} - \beta^l = \left(\mathbf{b}^l - \alpha^l\right)'\mathbf{C}^{-1}\left(\alpha^c + \alpha^l\right) - \beta^l. \tag{47}$$

Since each principal's surplus in the absence of a direct relationship with the farmers hinges on the efforts the farmers exert as a result of receiving compensation from the other principal, $\mathbf{b}^{c'}\mathbf{C}^{-1}\alpha^l$

[28] See Dixit (1996) and Holmstrom and Milgrom (1997).

for the Center and respectively $\mathbf{b}^{l'}\mathbf{C}^{-1}\alpha^c$, we subtract these and obtain each principal's surplus from their *own* respective contractual relationship with the farmers,

$$E\left[\mathbf{b}^{c'}\mathbf{x}\right] - \alpha^{c'}\mathbf{x} - \beta^c = \left(\mathbf{b}^c - \alpha^c\right)' \mathbf{C}^{-1}\alpha^c - \alpha^c\mathbf{C}^{-1}\alpha^l - \beta^c \tag{48}$$

and

$$E\left[\mathbf{b}^{l'}\mathbf{x}\right] - \alpha^{l'}\mathbf{x} - \beta^l = \left(\mathbf{b}^l - \alpha^l\right)' \mathbf{C}^{-1}\alpha^l - \alpha^l\mathbf{C}^{-1}\alpha^c - \beta^l. \tag{49}$$

Now each principal maximizes its own joint surplus with the farmers. Summing up (48) respectively (49) with the farmers' (45) and taking the first order condition with regard to α^c and α^l yields the principals' respective best response functions

$$\mathbf{b}^c = \alpha^c + r\mathbf{C}\mathbf{\Psi}\alpha \tag{50}$$

and

$$\mathbf{b}^l = \alpha^l + r\mathbf{C}\mathbf{\Psi}\alpha, \tag{51}$$

both adding up to the combined principal benefits of

$$\mathbf{b} = \left(I + 2r\mathbf{C}\mathbf{\Psi}\right)\alpha. \tag{52}$$

Combining (50) respectively (51) with (52) and rearranging yields each principals compensation

$$\alpha^c = \mathbf{b}^c - r\mathbf{C}\mathbf{\Psi}\left(\mathbf{I} + 2r\mathbf{C}\mathbf{\Psi}\right)^{-1}\mathbf{b}$$

and

$$\alpha^l = \mathbf{b}^l - r\mathbf{C}\mathbf{\Psi}\left(\mathbf{I} + 2r\mathbf{C}\mathbf{\Psi}\right)^{-1}\mathbf{b}.$$

Now we turn to the farmers' resulting effort levels. Since r is positive, $\mathbf{b} - \alpha = 2r\mathbf{C}\mathbf{\Psi}\alpha > 0$, comparing and we infer that the effort level under moral hazard is lower powered than under the fully observed effort case,

$$\mathbf{t}^{MH} = \mathbf{C}^{-1}\alpha < \mathbf{C}^{-1}\mathbf{b} = \mathbf{t}^{FO}. \tag{53}$$

The resulting farmers' effort vector is derived from (35), (52) and (44) to be $\mathbf{t}^{MH} = \mathbf{C}^{-1}\left[\left(I + 2r\mathbf{C}\mathbf{\Psi}\right)^{-1}\mathbf{b}\right]$, which through substitution yields

$$\begin{pmatrix} t_0^{MH} \\ t_b^{MH} \end{pmatrix} = \begin{pmatrix} \left(2b_0 - c_a\right) / \left(c_0 + 2r\psi_0 c_0^2\right) \\ \left(2b_b - h^c - h^l\right) / \left(c_b + 2r\psi_b c_b^2\right) \end{pmatrix}, \tag{54}$$

where ψ_0 and ψ_b are the variances of the farmers' normally distributed random error ε of efforts. The principals' payoffs are now distinct: For the Center we use (46) and (54) to calculate expected surplus of $\mathbf{b}^{c'}\mathbf{t} - \alpha^{c'}\mathbf{t} - \beta^c$ which yields

$$\frac{2r\psi_0}{\left(1 + 2r\psi_0 c_0\right)^2}\left(b_0 - c_a\right)\left(2b_0 - c_a\right) + \frac{2r\psi_b}{\left(1 + 2r\psi_b c_b\right)^2}\left(b_b - h^c\right)\left(2b_b - h^c - h^l\right) - \beta^c \tag{55}$$

and the corresponding expression for the Local Group's expected surplus $\mathbf{b}^{l\prime}\mathbf{t} - \alpha^{l\prime}\mathbf{t} - \beta^{c}$, which leads to

$$\frac{2r\psi_0}{\left(1+2r\psi_0 c_0\right)^2} b_0 \left(2b_0 - c_a\right) + \frac{2r\psi_b}{\left(1+2r\psi_b c_b\right)^2} \left(b_b - h^l\right)\left(2b_b - h^c - h^l\right) - \beta^l. \tag{56}$$

We also calculate the farmers' aggregate compensation amounts to

$$\alpha'\mathbf{t} + \beta - \frac{1}{2}\mathbf{t}^{MH\prime}\mathbf{C}\mathbf{t}^{MH} = \frac{1}{2}\left[\frac{\left(2b_0 - c_a\right)^2}{c_0\left(1+2r\psi_0 c_0\right)^2} + \frac{\left(2b_b - h^c - h^l\right)^2}{c_b\left(1+2r\psi_b c_b\right)^2}\right] + b. \tag{57}$$

Finally, the total combined surplus can be calculated by summing-up the Center's (55) and the Local Group's (56) surplus and the farmers' compensation (57) and simplifying to

$$S^{MH} = \frac{1}{2}\left[\frac{\left(2b_0 - c_a\right)^2\left(1+4r\psi_0 c_0\right)}{c_0\left(1+2r\psi_0 c_0\right)^2} + \frac{\left(2b_b - h^c - h^l\right)^2\left(1+4r\psi_b c_b\right)}{c_b\left(1+2r\psi_b c_b\right)^2}\right],$$

which is lower than in the fully observable, benevolent and cooperative principals case

$$S^{FO} = \frac{1}{2}\left[\frac{\left(2b_0 - c_a\right)^2}{c_0} + \frac{\left(2b_b - h^c - h^l\right)^2}{c_b}\right]$$

since $0 < \frac{(1+4r\psi_0 c_0)}{(1+2r\psi_0 c_0)^2} < 1$ and $0 < \frac{(1+4r\psi_b c_b)}{(1+2r\psi_b c_b)^2} < 1$.