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Economy-wide impacts of REDD when there is political influence

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A R T I C L E   I N F O

A B S T R A C T

National-level strategies for reducing emissions from deforestation and degradation (REDD), financed by international transfers, have begun to emerge. A three-sector model is developed to explore the economy-wide effects of two policies implemented by a government participating in REDD that differ in how they bring together incentives and benefit sharing: an incentive payment scheme where these are intrinsically linked and taxes where they are separated. Two sectors utilise forest as an input to production, one in which forest is substitutable for labour, producing a carbon externality, and one in which forest and labour are complements and where forest is used sustainably. Two important effects determine model outcomes. First, the government factors in general equilibrium effects when determining the efficient payment level. This implies that the level of international transfers is not fully passed through to the forest-using sectors. Second, even though the sustainable sector receives no incentive payment it can increase in size through the effect of REDD payments on markets. With political influence, where incentives and benefit sharing are linked the forest-using sectors may lobby for lower payment rates for themselves in order to create a larger international transfer. Where there is a separation between incentives and benefit-sharing this effect disappears. The findings indicate that REDD may be less cost-effective than envisioned at the international level.

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1. Introduction

Reducing emissions from deforestation and forest degradation (REDD) in tropical countries could address up to a fifth of global, anthropogenic greenhouse gas emissions (Van der Werf et al., 2009). Since Stern (2006), REDD has emerged as a potentially cost-effective strategy for reducing emissions, an argument based on comparing the marginal abatement costs of different mitigation strategies. Despite on-going uncertainty regarding the design of an international REDD mechanism under the United Nations Framework Convention on Climate Change (UNFCCC), national-level strategies and policy frameworks are likely to play an important role (Wertz-Kanounnikoff and Angelsen, 2009). Indeed, countries are already developing strategies that include REDD. For example, Guyana has instituted its Low Carbon Development Strategy, and the World Bank's Forest Carbon Partnership Facility (FCPF) is involved in developing similar strategies in a number of countries.

Through such strategies, governments take on responsibility for attracting finance, designing and implementing policies for achieving REDD, distributing benefits, and setting baselines for emissions reductions. Thus, they allow for the possibility of an economy-wide approach to REDD with a single baseline for emissions across all relevant, forest-using sectors.[1] Yet in many tropical countries these sectors are often characterised by weak governance and endemic rent seeking (Amacher, 2006; Koyuncu and Yilmaz, 2008; Palmer, 2005). Introducing international REDD finance could potentially redirect rent-seeking efforts towards the capture of any benefits that REDD may bring (see Myers, 2007).

In this paper, we develop a model of a small open economy in order to examine the impacts of two policy instruments implemented through a national REDD strategy: incentive payments (or payments of environmental services) along with input and output taxes.[2] This serves to address the following three questions. First, what are the economy-wide, general equilibrium effects of implementing REDD? Second, how might these affect government policies for achieving REDD? And third, how do these effects change with political influence from sectors affected by REDD?

By shifting labour, capital and other inputs between sectors – via changes in relative prices – REDD is likely to have broad economic impacts. For example, REDD may be used to encourage the growth of sectors that are less directly dependent on forest as an input to production. However, input and output prices and the relative profitability of all sectors may also change. Recent research has begun to address these potential impacts. For example, Ibarraran and Boyd (2010) examined the multiplier and distributional effects of REDD policies in Mexico using a computable general equilibrium model. Opening the general equilibrium 'black box', Ollivier (2012) developed a growth model with land-conversion dynamics in a two-sector economy and assessed the long-term impacts of an international REDD transfer. Our model of a multi-sector economy also adopts a national REDD strategy financed by an international transfer. Yet, we use it in order to examine how different policies might affect different sectors, including their use of forest. In this respect, we follow earlier work concerned with the impacts of policies on deforestation in a general equilibrium setting (e.g. Deacon, 1995), as well as research concerned with the general equilibrium effects of other, climate change-related policies (e.g. Rivers, 2013; Aronsson et al., 2010).

We depart from previous work on the general equilibrium effects of REDD by considering the potential for political influence on REDD policy making. Specifically, we adopt the common-agency model of Grossman and Helpman (1994), who used it to investigate the impact of lobby group influence on trade policy. Subsequently, it has been applied to examine the role of political influence in public policy-making, including environmental taxes and subsidies (Fredriksson, 1997), environmental protection (Schleich, 1997; Yu, 2005), and forest conservation (Eerola, 2004; Jussila, 2003). To our knowledge, our paper is the first to apply it to an international-level incentive like REDD. Previous research illustrated how policies such as taxes shift the relative prices of inputs or outputs, returning

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[1] This could account for the release of carbon embodied in biomass even if it 'leaked' from one sector to another as a consequence of policy implementation (see Murray, 2009).

[2] Policy options for REDD mirror those of forest conservation more generally (see, for example, Angelsen, 2008, 2009, 2010; Daviet, 2009; Palmer, 2011; Pfaff et al., 2010). Incentive payments schemes have been central to REDD policy discussions in recent years.

revenue on a per-capita basis. By contrast, we show how incentive payments shift the relative price of inputs, and provide a series of income transfers to different sectors. Indeed, the size of the shift in relative prices helps determine the level of income transfer.

These income transfers can be potentially unequal, which suggests implications for benefit sharing, a key concern of REDD policy design (see Costenbader, 2011). Two discourses have been identified (Luttrell et al., 2012). The first concerns the *effectiveness and efficiency* of REDD, where benefits are used as incentives to change the behaviour of actors engaged in deforestation. The second focuses on *equity* in which benefits are used, for example, to reward forest users with legal rights or a history of good forest stewardship. Arguably, REDD has to be perceived as 'fair' by forest users and other REDD stakeholders in order to provide legitimacy and support for policy. Different policies implemented by a government with a national-level REDD strategy may have different implications for benefit sharing. Delacote et al. (2014) examine the distributional implications of incentive payments conditional on the government's policy objectives. Our model, on the other hand, allows us to compare the implications of a payment scheme that directly links incentives to income transfers, with those of taxes, which offer a complete separation between incentives and income transfers.

Introduced in Section 2, our model adopts the consumer and producer formulation of Fredriksson (1997) and incorporates three sectors similar to the framework of Jussila (2003). We consider two sectors that share in the benefits from REDD, both of which use forest as an input to production. In the first, 'agriculture', forest is substitutable with labour and use of the forest produces a carbon externality. In the second, 'sustainable forest management' (SFM), forest is used in joint production with labour, and there is no carbon externality. Similar to the models of, for example, Ferraro and Simpson (2002), Groom and Palmer (2010), and Muller and Albers (2004), this sector represents non-extractive yet productive use of forests, e.g. eco-tourism, sustainable forestry and biodiversity prospecting.[3] We depart from those models by considering joint production in a general rather than partial equilibrium setting. REDD is arguably likely to be as much about shifting forest to joint production activities as it is about using incentives to set aside forest.

An international incentive is offered to the government of the REDD host country as an exogenous payment per unit of carbon externality reduced below a business-as-usual baseline. For example, by the FCPF or a country seeking to finance REDD via bilateral arrangements in the mould of those negotiated between Norway and respectively, Brazil, Guyana, and Indonesia.[4] In order to reduce emissions and distribute benefits, the government first implements a payment scheme. As shown in Section 3, the government chooses the size of payment offered to each forest-using sector. As this choice determines the scale of the reduction in deforestation it also determines the size of the total international incentive received, or the 'benefit pie', and the distribution of these benefits between sectors. Increasing the payment to the agricultural sector strengthens its incentive to reduce forest use. This helps create a larger benefit pie, a larger share of which is distributed to that sector. By contrast, reducing the payment has the opposite effect, reducing both the pie and the sector's share.

We find that the international incentive made to a government adopting a national REDD strategy may not be equivalent to the incentive transferred by that government to participating sectors. A rational government will factor in two categories of general equilibrium effects – forest price effects that result from the impacts of REDD policy on relative prices, and income transfer effects that result from transfers of REDD benefits. Indeed, REDD may be less cost-effective than originally envisaged by Stern (2006) onwards. We also find that payments to the agricultural sector drives growth of the SFM sector through its effect on factor input markets.

Political influence is introduced in Section 4. In previous work by, e.g. Fredriksson (1997), Jussila (2003), 'contributions' are paid to an incumbent government seeking re-election. These contributions are a valuation by the government of some element of the welfare change of one specific sector over others in response to a policy change. This valuation may be monetary or it may be due to preferences

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[3] Such activities play an important role in small economies like Costa Rica.

[4] Similar to many current REDD initiatives these are dependent on public funds. While some REDD projects are financed from the sale of Voluntary Emissions Reductions, carbon markets play a relatively small role compared to public financing initiatives (Peters-Stanley et al., 2013). Yet the development of regional carbon markets that accept credits from REDD, such as California's cap-and-trade system, could boost the future role of markets to finance REDD policy initiatives.

for a particular sector, for example, due to interest group lobbying, the political make-up of the country or a perception that protection of a particular sector offers long-term benefits to the country. In our model, giving contributions is conceived as having political influence, which can be offered by either forest-using sector.

When the agricultural sector has stronger political influence, the direction of change in incentives to either sector is indeterminate and depends on the relative changes in the forest price and income transfer effects. Which effect dominates depends on the dependence of the agricultural sector on the forest input, the relative ease of switching between sectors, and the deforestation baseline against which the REDD payment is made. A similar indeterminate result is found when the SFM sector has political influence. This leads to the counter-intuitive result that under some conditions the SFM sector may lobby for a lower payment rate to its own sector in order to create a stronger incentive to reduce forest use in the agricultural sector and boost the size of the international incentive.

In Section 5, we consider input and output taxes in addition to relaxing the assumption of perfect labour markets. Taxes are shown to influence factor and output prices as well as producers and consumers. In contrast to the payment scheme, the international incentive is added to tax revenue and redistributed on a per-capita basis thus separating the incentive from income transfers. Indeed, there can be a fully equitable distribution of benefits. But when the agricultural sector has influence, input tax rates are reduced. By contrast, taxes rise when the SFM sector has influence. Our results are robust to relaxing the assumption of perfect labour markets. Section 6 discusses the results before concluding.

2. Model set-up

2.1. Production

The majority of countries likely to be recipients of REDD finance can be characterised as small, open economies and thus, we set up our model in this way. There are three producing sectors, two of which consist of local monopolies that utilise a forest input, f, in production. The first of these sectors, 'agriculture' (β), has two inputs, f, and labour, l, using a diminishing-returns-to-scale technology.[5] In utilising land under forest cover, the sector produces carbon dioxide emissions from forest clearance. It represents a forest-extractive industry, which varies from place to place, for example, soya or cattle ranching in Brazil, and palm oil in Indonesia.[6]

In the second forest-using sector (γ), 'sustainable forest management' (SFM), forest is an input, again in combination with labour. This sector is characterised by joint production, i.e. labour and forest are strict complements. Joint production can occur in non-extractive forest-using sectors such as ecotourism, biodiversity prospecting, and non-timber forest product extraction. Relatively undisturbed forest ecosystems are employed as inputs, which, combined with labour, produce an output, e.g. tourist excursions, chemical compounds, or fruits. Thus, use of the forest in this sector does not produce emissions of carbon dioxide, i.e. production occurs without forest clearance.

The third sector is termed industry (α), which acts as a numéraire representing all other production in the economy. It uses a single factor, labour, using constant returns to scale technology and has an input–output coefficient of one.

The three sectors produce goods x_α, x_β and x_γ with prices, $p_{i \in \alpha, \beta, \gamma}$ exogenously determined on the world market, with p_α normalised to one. The economy is populated by N individuals, each of whom has a single unit of labour, with N normalised to one. Individuals have a number of roles in this model. First, they can sell their labour endowment to one of the three sectors ('workers'). Second a subset of individuals owns forest, which they can lease either to the agriculture sector or to the SFM

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[5] This follows similar assumptions made by Eerola (2004).
[6] We note that these land uses may have different environmental implications, although they are analogous for the purposes of our model.

sector through a concessionaire system to local monopolies in return for a rent.[7] Third a subset act as owners of the local monopolies in the agricultural and SFM sectors and they receive profits from these sectors. Fourth, they consume goods from all three sectors ('consumers'). Workers can sell their labour endowment to any sector. An assumed competitive labour market equilibrium implies wages are equated in all sectors at a level, w.[8] We discuss the implication of relaxing the assumption of competitive labour markets in Section 5.

Similar to Ollivier (2012), it is assumed that barriers exist such that only those individuals with existing forest resources can engage in the forest market. Barriers could be, for example, economic, social, geographical or institutional. This assumption allows a focus on the effects of REDD in two specific ways. First, on the potential of REDD to incentivise the agricultural sector to become less forest intensive and second, in providing incentives to landowners to lease land to the SFM sector instead of the agricultural sector. It is assumed that this switch is costless. Our static model abstracts from the dynamics of forest growth, although the switch from agriculture to SFM is likely to require time for forest to be rehabilitated. Thus, the cost of this switch may exceed the cost of switching from SFM to agriculture due to the time needed for forest regrowth. Yet, switching from SFM to agriculture will also involve other costs, e.g. for forest conversion.[9] Imposing a constraint on the ability of landowners to move from agriculture to SFM however does not materially alter the results; it merely reduces the level of some of the differentials thus reducing the scale of the general equilibrium effects.

Operators maximise profits, and they can be aggregated together within sectors to give the restricted profit function $\pi_i(p_i, z)$ for each sector where z is the price of the forest input, f. Optimal output y_i^* is derived as the level of output that solves:

$$p_i = \frac{\partial c_i}{\partial y_i} \quad \text{for} \quad i \in \beta, \gamma \tag{1}$$

where $\partial c_i / \partial y_i$ is the partial differential of the cost function, $c_i(f_i, l_i, z, w)$. Given optimal output, the level of forest demand f_i and labour demand l_i are the solutions to:

$$\min c_i(f_i, l_i, z, w) \tag{2}$$

z is determined in a forest market and is the price that clears the market, based on the requirement that:

$$f_\beta^* + f_\gamma^* = f_t^* \tag{3}$$

where f_t^* is the total amount of forest in the economy.[10] This can be interpreted as the total, state-owned area of forest where production is legally sanctioned, i.e. excluding protected areas, and where production might be profitable.

The determination of z clears all markets and defines optimal output, y_i^*, realised forest input demands, f_i^*, labour input demands, l_i^*, forest input price, z and wages, w. These in turn determine profit levels in each sector.

2.2. Consumption

Consumers, who are assumed to have identical preferences, consume all three goods and their utility is an additive function of consumption of the goods, $x_\alpha, x_\beta, x_\gamma$:

$$U = x_\alpha + x_\beta + x_\gamma \tag{4}$$

where x_α is the total consumption of the numéraire and x_β, x_γ is the total consumption of each production good. Consumers are subject to a budget constraint and are assumed to use all their income to purchase the three goods. Thus:

$$Y = x_\alpha + p_\beta^* \cdot x_\beta + p_\gamma^* \cdot x_\gamma \tag{5}$$

where p_β^* is the world market price for x_β and p_γ^* is the world market price for x_γ normalised by the numéraire price, and Y is the income of the population as a whole.

From Eqs. (4) and (5) an indirect utility function for the population, V, can be derived:

$$V = Y + u(d_\beta(p_\beta^*)) - p_\beta^* d_\beta(p_\beta^*) + u(d_\gamma(p_\gamma^*)) - p_\gamma^* d_\gamma(p_\gamma^*) \tag{6}$$

where $d_\beta(p_\beta^*)$ and $d_\gamma(p_\gamma^*)$ are the realisations of the demand function for consumers at world market prices p_β^*, p_γ^* and $u_i(d(p_i^*))$ is the resulting utility from that demand. The last four terms on the right-hand side of (6) thus represent consumer surplus from consumption of the production goods. Given exogenously determined prices, the values for consumer surplus are fixed and utility is a direct function of income.[11]

2.3. Income

Income is generated from three sources, labour income, forest rents and profits. The total income of each sector is the earnings from all individuals relating to that sector, the wages of workers employed, the rents of landowners and the profits of the local monopolies:

$$Y_i = l_i w + z f_i + \pi_i \tag{7}$$

for $i = \alpha, \beta, \gamma$, where l_i is the normalised labour demand in each sector.[12]

Social welfare, W, is given by the aggregate indirect utility of the population, which follows from Eqs. (6) and (7) as:

$$W = w + z(f_\beta^* + f_\gamma^*) + \pi_\beta + \pi_\gamma + u(d_\beta(p_\beta^*)) - p_\beta^* d_\beta(p_\beta^*) + u(d_\gamma(p_\gamma^*)) - p_\gamma^* d_\gamma(p_\gamma^*) \tag{8}$$

We assume that each unit of forest input used in agriculture, f_β, creates one unit of carbon dioxide, and $F^* = f_\beta^*$ is the baseline level of carbon dioxide emissions from deforestation, i.e. before the implementation of REDD.

3. Introducing REDD

A REDD strategy is implemented by the government of the economy ('the government'). It is offered an incentive by an international actor at an exogenous rate, χ, per-unit of carbon dioxide. This rate is either set by a carbon market or by the international actor with the aim of reducing the generation of carbon dioxide from deforestation below the baseline level, F^*, with $\chi > 0$ and payments of zero for: $f_\beta^* > F^*$.

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[11] This follows similar assumptions made by Fredriksson (1997).
[12] Due to the assumption of constant-to-returns to scale technology in the industry sector π_α is zero and is therefore excluded.

3.1. Payment scheme

The payment scheme consists of a financial transfer to both the agricultural and SFM sectors with the total equal to the payment received by the government from the international actor. Note that the rest of the economy, represented by industry in our model, is excluded from the benefits of REDD. We justify the inclusion of SFM due to its use of forest as an input to production. This also allows us to explore the implications of the government's decision of how to split the pie, in particular should it decide to reduce the payment to the agriculture sector. Indeed, we find similar results if instead the government chose to retain REDD finance or distribute it to the industrial sector. A payment, ρ, is offered to each sector, given by:

$$\rho_i = \varphi_i(F^* - f_\beta^*), \quad i \in \beta, \gamma \tag{9}$$

with $\chi = \sum_{i=\beta,\gamma} \varphi_i$ and $\varphi_i > 0$. Thus, φ_i denotes the payment rate. It is assumed that payments accrue to the local monopolies with incentives passed on the landowners through rents.[13] While the SFM sector does not engage in deforestation and emits no carbon dioxide, this sector receives payments, the size of which is dependent on the extent of deforestation in the agricultural sector. The payment scheme splits the entire 'benefit pie' from the international incentive between the two sectors. Yet, the size of this pie is also dependent on the extent of deforestation in the agricultural sector.

The conceptual timing of the REDD scheme is as follows:

1. The exogenously determined payment rate per unit of carbon dioxide emitted from deforestation is communicated to the government.
2. The government decides the rate of payment it will offer to the two forest-using sectors, and communicates this to the sectors.
3. The sectors decide their level of inputs and outputs and produce carbon dioxide emissions.
4. The international actor provides the finance based on the exogenous rate and the realised quantity of carbon dioxide from deforestation.
5. The government passes through the payment to the sectors based on the rate communicated in step 2.

In the agricultural sector, the payment scheme offers a share in the benefits from REDD in two ways, which correspond to the two discourses identified by Luttrell et al. (2012). First, there is an income transfer equal to the agricultural sector's payment rate multiplied by baseline forest use, F^* ('equity'). Second, the agricultural sector faces an increase in the forest input price, which represents the incentive to reduce (future) deforestation ('efficiency, effectiveness'). Government-coordinated payment schemes that combine incentives with income transfers are relatively common across the world. Such schemes often attempt to improve environmental outcomes while tackling rural poverty. For example, Ecuador's *Socio Bosque* programme offers payment rates dependent on the size of the area put under conservation (de Koning et al., 2011). Thus, poorer landowners who control smaller areas are offered larger payments per ha than those with larger landholdings.

The SFM sector does not face incentives to reduce deforestation but receives an income transfer. This is equal to the SFM sector's payment rate multiplied by the reduction in carbon dioxide emissions from deforestation in the agricultural sector. In our framework, the income transfer to the SFM sector can be interpreted as a reward for good forest stewardship and hence, plays no role in the sector's production decision. An example of such support can be seen in the *Bolsa Floresta* project in Brazil, which was observed to benefit 30,000 forest dwellers across 15 'Sustainable Development Reserves' (Börner et al., 2013). Cash is transferred to families in exchange for promises to, e.g. send children to school, participate in local organisations, and undertake conservation activities.

The payment scheme has the effect of driving a wedge in forest input prices between the two sectors, gross of the payment. It changes the relative prices of the forest input and redistributes the

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[13] If payments are offered to consumers of agricultural output after the production decision is made there will be no effect on quantities of forest input.

revenue in proportion to the change in relative prices. Through the market, forest prices net of payment are equalised at a new equilibrium.

The introduction of the payment scheme amends the profit function of the agricultural sector to:

$$\pi'_\beta = \pi_\beta[p^*_\beta, x_\beta, z + \varphi_\beta, f^*_\beta, w, l_\beta] + \varphi_\beta F^* \tag{10}$$

with the profit function of the SFM sector becoming:

$$\pi'_\gamma = \pi_\gamma[p^*_\gamma, x_\gamma, z, f^*_\gamma, w, l_\gamma] + \varphi_\gamma(F^* - f^*_\beta) \tag{11}$$

The inclusion of REDD payments also means that both the forest price, z, and the forest input level in agriculture, f^*_β, become functions of φ_β, the payment rate to the agricultural sector. Intuitively, the payment affects the returns from the use of forest in the agricultural sector, which affects the demand schedules and in turn the equilibrium forest price. By increasing the forest price to the agricultural sector gross of the payment it reduces the sector's returns on forest. This leads to a lower demand for the factor, which implies a lower equilibrium forest price thus determining the optimal allocation of forest between the two sectors. The fall in agricultural profits and forest prices results in landowners leasing forest to the SFM sector instead of the agricultural sector.

Combining (10) and (11) with (8) gives the amended social welfare function under REDD as:

$$W = w + zf^*_t + \pi'_\beta + \pi'_\gamma + u(d_\beta(p^*_\beta)) - p^*_\beta d_\beta(p^*_\beta) + u(d_\gamma(p^*_\gamma)) - p^*_\gamma d_\gamma(p^*_\gamma) \tag{12}$$

From (12) the government's maximisation problem is thus:

$$\max_{\varphi_\beta, \varphi_\gamma} W = w + zf^*_t + \pi'_\beta[p^*_\beta, w, z + \varphi_\beta, \beta, f^*_\beta, x_\beta, \varphi_\beta] + \pi'_\gamma[p^*_\gamma, x_\gamma, z, f^*_\gamma, w, \gamma, \varphi_\gamma, f^*_\beta] + CS \tag{13}$$

subject to: $\sum_{i=\beta,\gamma} \varphi_i = \chi$ where the constant level of consumer surplus relating to the two production goods is given by:[14]

$$CS = u(d_\beta(p^*_\beta)) - p^*_\beta d_\beta(p^*_\beta) + u(d_\gamma(p^*_\gamma)) - p^*_\gamma d_\gamma(p^*_\gamma)$$

We solve the maximisation problem using the Lagrangian method with the maximisation given from (13) as:

$$W = w + zf^*_t + \pi'_\beta[p^*_\beta, w, z + \varphi_\beta, \beta, f^*_\beta, x_\beta, \varphi_\beta] + \pi'_\gamma[p^*_\gamma, x_\gamma, z, f^*_\gamma, w, \gamma, \varphi_\gamma, f^*_\beta]$$
$$+ \lambda(\varphi_\beta + \varphi_\gamma - \chi) \tag{14}$$

Differentiating (14) gives the first-order conditions of:

$$\frac{\partial W}{\partial \varphi_\beta} = \frac{\partial w}{\partial \varphi_\beta} + \frac{\partial z}{\partial \varphi_\beta} f^*_t + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial \varphi_\beta} + \lambda \tag{15}$$

$$\frac{\partial W}{\partial \varphi_\gamma} = (F^* - f^*_\beta) + \lambda \tag{16}$$

$$\frac{\partial W}{\partial \lambda} = \varphi_\beta + \varphi_\gamma - \chi \tag{17}$$

These conditions are rearranged to give the following payment rates, made to each forest-using sector:

$$\varphi_\beta = \chi - \left(\frac{\partial w}{\partial f^*_\beta} + \frac{\partial z}{\partial f^*_\beta} f^*_t + \frac{\partial \pi_\beta}{\partial f^*_\beta} + \frac{\partial \pi_\gamma}{\partial f^*_\beta} + \frac{f^*_\beta}{\frac{\partial f^*_\beta}{\partial \varphi_\beta}} \right) \tag{18}$$

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[14] In subsequent discussions of the model we drop CS from the welfare equation as it is a constant and hence, is not affected by policy choices.

$$\varphi_\gamma = \frac{\partial w}{\partial f_\beta^*} + \frac{\partial z}{\partial f_\beta^*} f_t^* + \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \tag{19}$$

with the following constraints:

$$0 \le \varphi_\beta, \varphi_\gamma \le \chi$$

The bracketed term in Eq. (18) represents the general equilibrium effects of the payment scheme. Thus, the amount transferred to the agricultural sector is equal to the international transfer minus the general equilibrium effects resulting from the implementation of the scheme.

Given the distinction between the incentive and income transfer components of the payment scheme, the general equilibrium effects can be identified as follows. First, a 'forest price effect' comprises the impact from the adjustment in the relative price of forest between the sectors: $\frac{\partial w}{\partial f_\beta^*} + \frac{\partial z}{\partial f_\beta^*} f_t^* + \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*}$. This consists of the effect of this price change, moderated through the optimal allocation of forest in the agricultural sector, on the profitability of each sector, wage income and forest rents. An 'income transfer effect' is identified as the change in the scale of the income transfer as the payment rate changes: $\frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$.

The following assumptions are made regarding the direction of the relevant partial derivatives: $\frac{\partial \pi_\beta}{\partial f_\beta^*} > 0, \quad \frac{\partial \pi_\gamma}{\partial f_\beta^*} < 0, \quad \frac{\partial f_\beta^*}{\partial \varphi_\beta} < 0, \quad \frac{\partial z}{\partial f_\beta^*} > 0, \quad \frac{\partial w}{\partial f_\beta^*} < 0.$

With respect to the first partial derivative, an increase in the agriculture sector's demand for forest, f_β^*, will, ceteris paribus, increase profits as it allows greater production with the proviso that the increase in f_β^* will also raise z. It is assumed that the first of these effects always dominates but at a decreasing rate implying: $\partial^2 \pi_\beta / \partial f_\beta^{*2} < 0$. An increase in f_β^*, reduces profits in the SFM sector (the second partial derivative) as it both restricts the amount of forest available in that sector, reducing production, and drives up the forest input price, z. With joint production technology, the scale of this effect is independent of the level of f_β^*: $\partial^2 \pi_\gamma / \partial f_\beta^{*2} = 0$.

An increase in the payment level to the agricultural sector reduces the level of forest input demand in that sector (the third partial derivative) since it increases overall marginal costs, reducing the level of optimal output, y_β^*, as well as increasing the relative price of forest against labour. The latter encourages substitution between the factors for any given level of output. It also encourages a switch away from the agricultural sector as it depresses profits in that sector. These effects are constant with respect to the payment level: $\partial^2 f_\beta^* / \partial \varphi_\beta^2 = 0$.

Moving to the final partial derivative, an increase in forest demand in the agricultural sector leads to higher demand for labour in that sector. It also leads to less forest available for the SFM sector, resulting in a reduction in demand for labour there. The effect on overall wage rates will depend on the scale of these two effects. Given our assumptions regarding diminishing returns to scale in the agricultural sector and joint production in the SFM sector, the reduction in demand for labour in the SFM sector is likely to exceed the increase in labour demand in the agricultural sector thus implying a net negative effect on wages.

In sum, payments to the agricultural sector, and thus incentives to reduce forest use, will be greater when: the dependence of the agricultural sector on forest is smaller; the responsiveness of the SFM sector to increases in forest use in agriculture is greater (either through restrictions on forest to that sector, or through an increase in its price); forest use in agriculture is greater; and the impact of the payment on reducing deforestation is smaller.[15]

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[15] Given our assumptions, an interior solution to the model is found as long as φ_γ is bounded by 0 and χ. The first term of (19) is negative, the second and third are positive and the fourth and fifth are negative, which along with the assumption of a

4. Interest group influence

In this section, either of the forest-using sectors can exert some influence on government decision making above and beyond its level of overall social welfare. To examine the effect on payment rates of moving away from the social welfare maximising payment rate discussed in Section 3, we follow Fredriksson (1997) who in turn builds on the characterisation of a menu auction problem by Bernhein and Whinston (1986) and the solution to the political equilibrium identified by Grossman and Helpman (1994).

We first assume that a lobby group can offer a certain amount of influence on government decision-making. What is often termed 'contributions' in the literature we characterise more generally as 'political influence'. Influence may originate from economic power, the organisation of industry groups, or the ability to offer payments or campaign contributions directly. The government welfare function, G, now becomes:

$$G = W + \mu C_{i \in \beta, \gamma} \tag{20}$$

where W is the overall social welfare, C_i is the level of influence offered and μ is the relative weight put on influence and overall social welfare by the government. The term μ denotes the degree of lobby group influence on government decision-making. It can represent the extent to which governments make decisions for the good of their entire population versus the extent they are made to benefit a certain subset of the population, i.e. those with political influence. If $\mu = 0$, then the model is solved in the same way as in Section 3. C_i is assumed to be a continuous, differentiable function on a policy vector, E. This vector is populated by all the different feasible levels of the payment rate to the agricultural sector: φ_β. It thus represents all the possible policy options available to the government.

The model takes the following steps:

- The agricultural or SFM sector has access to, and can influence, government decision making.
- This influence is valued by the government along with overall social welfare.
- The sector with this access offers the government a menu of levels of influence based on each level of the policy vector E.
- The government then chooses from its menu, E, a desired realisation of the policy, given as e, and receives the identified level of influence.

Following Fredriksson (1997), $(\{C_i\}_{i \in \beta, \gamma}, [e])$ is identified as a Subgame Perfect Nash Equilibrium if and only if four conditions hold: the level of influence must be feasible, i.e. non-negative and less than total income; the government sets the policy instrument at a level that maximises its own welfare given the influence schedule on offer; the policy instrument maximises the joint welfare of the lobby group and the government; and, there exists an 'anchor' level of influence – that is, a least-favoured policy option in which influence is zero.

The model is then solved for the case when either sector attempts to influence government policy making.[16] Following Grossman and Helpman (1994) and Fredriksson (1997), influence is 'locally truthful'. This means that any change in welfare is reflected in a change in influence. Hence, if the welfare of one sector increases, it increases their level of influence proportionately. The condition for the government's maximisation of its welfare function (20) is derived as:

$$\nabla W + \mu \nabla W_i = 0 \tag{21}$$

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payment with a lower-bound value of zero, gives an optimum solution if: $\left| \frac{\partial z}{\partial f_\beta^*} f_t^* + \frac{\partial \pi_\beta}{\partial f_\beta^*} \right| > \left| \frac{\partial w}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right|$. Corner solutions exist where payments to either the agricultural or SFM sector are zero. However, discussion of these solutions is excluded here: since the entire 'pie' is offered to one sector or the other, they do not provide any interesting insights for REDD policy.

[16] When both sectors offer contributions the model simplifies to the case where only social welfare is considered since the two sectors are valued equally.

where W_i is the welfare of the sector exerting influence on the government.[17] Condition (21) implies that instead of the government imposing the policy instrument up to the point where the marginal benefit to society is zero, it imposes the policy up to the point where a weighted sum of change in social welfare and the influential sector's change in welfare are zero.

A limitation of the Grossman and Helpman framework is that it requires, at any time, one sector not to be involved in lobbying activity. If all sectors lobby together the result is equivalent to an absence of lobbying activity. This is a limitation of the model since all sectors are likely to lobby at the same time in many cases. To get around this, the government is assumed to value the sector which lobbies most effectively thus disregarding the efforts of the less-effective sector altogether.

In the context of deforestation, the agricultural sector is likely to be the most influential lobby group in most situations. The farm sector lobby is a crucial political influence in countries like Brazil and Indonesia – witness the recent lobbying in relation to the revision of the Amazon forest code (Los Angeles Times, 2012). However, there are contexts in which the environmental or sustainable forestry lobby group has significant influence. Environmental NGOs have played a significant role in driving the creation of protected areas in many countries such as Madagascar (Brockington et al., 2008); environmental and sustainable forest management issues have driven the policy agenda in early REDD movers such as Guyana. Thus, we also examine the case where the SFM sector is more influential in order to derive the implications for REDD policy.

4.1. Agricultural sector influence

When the agricultural sector exerts influence the government chooses a level of policy instrument that solves:

$$\nabla W + \mu \nabla W_\beta = 0 \tag{22}$$

with the agricultural sector's welfare becoming:

$$W_\beta = w l_\beta + z f_\beta^* + \pi_\beta + \varphi_\beta F^* \tag{23}$$

Differentiating (23) gives:

$$\frac{\partial W_\beta}{\partial \varphi_\beta} = \frac{\partial w}{\partial \varphi_\beta} l_\beta + \frac{\partial l_\beta}{\partial \varphi_\beta} w + \frac{\partial z}{\partial \varphi_\beta} f_\beta^* + \frac{\partial f_\beta^*}{\partial \varphi_\beta} z + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* \tag{24}$$

Combining (22) and (24) with (15)–(17) gives the following first-order conditions:

$$\frac{\partial w}{\partial \varphi_\beta} + \frac{\partial z}{\partial \varphi_\beta} f_t^* + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f_\beta^*}{\partial \varphi_\beta} + \lambda$$

$$+ \mu \left(\frac{\partial w}{\partial \varphi_\beta} l_\beta + \frac{\partial l_\beta}{\partial \varphi_\beta} w + \frac{\partial z}{\partial \varphi_\beta} f_\beta^* + \frac{\partial f_\beta^*}{\partial \varphi_\beta} z + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* \right) = 0 \tag{25}$$

$$F^* - f_\beta^* + \lambda = 0 \tag{26}$$

$$\varphi_\beta + \varphi_\gamma - \chi = 0 \tag{27}$$

Combining (25)–(27) and rearranging yields the following:

$$\varphi_\beta = \chi - \left(\frac{\partial w}{\partial f_\beta^*}(1 + \mu l_\beta) + \frac{\partial z}{\partial f_\beta^*}(f_t^* + \mu f_\beta^*) + \frac{\partial \pi_\beta}{\partial f_\beta^*}(1 + \mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \mu \left(\frac{\partial l_\beta}{\partial f_\beta^*} w + z \right) + \frac{\mu F^* + f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right) \tag{28}$$

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[17] The welfare of the sector is assumed to consist of all the income accruing from that sector, whether rents to land-owners, profits and REDD payments to the local monopolies and wages to workers.

$$\varphi_\gamma = \frac{\partial w}{\partial f_\beta^*}(1 + \mu l_\beta) + \frac{\partial z}{\partial f_\beta^*}(f_t^* + \mu f_\beta^*) + \frac{\partial \pi_\beta}{\partial f_\beta^*}(1 + \mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \mu \left(\frac{\partial l_\beta}{\partial f_\beta^*}w + z\right) + \frac{\mu F^* + f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \tag{29}$$

By comparing (18) and (28) and (19) and (29) it can be seen that the government factors in slightly amended indirect effects of the payment scheme when determining the payment rate. Thus, the forest price and income transfer effects change when political influence is present. The impact on agricultural profit is given greater weight (as $\mu > 0$), thus reducing the payment to the agricultural sector, as does the amount of wages earned by labourers in the agricultural sector, and the rent received by landowners leasing forest to the agricultural sector. A new term is included in the forest price effect, which relates to how labour demand in the agricultural sector changes in relation to an increase in forest input demand, $\partial l_\beta/\partial f_\beta^*$, weighted by the wage rate and the relative weight of political influence. An additional term is included in the income transfer effect, $\frac{\mu F^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$.

It is assumed that $\partial l_\beta/\partial f_\beta^*$ is positive; holding other inputs equal an increase in forest demand will lead to an expansion in output. This increases labour demand in the agricultural sector, although at a diminishing rate as forest demand increases. An increase in forest demand also raises the relative price of forest vis-à-vis labour thus boosting labour demand further. This, in turn, increases the wages in the agricultural sector, leading to a movement of labour away from the other sectors in order to equalise wages. The inclusion of this effect will increase the forest price effect, reducing the payment level to the agricultural sector. By contrast, the additional term in the income transfer effect will tend to increase the payment to the agricultural sector. The net effect on deforestation therefore depends on whether the change in the forest price effect dominates the change in the income transfer effect, or vice versa.

If the change in the forest price effect is greater than the change in the income transfer effect then the agricultural sector lobbies for lower payments. This dampens incentives to reduce deforestation in that sector thus increasing forest input to production, f_β^*. This in turn increases agricultural profits, $\partial \pi_\beta/\partial f_\beta^*$. These two effects will partially offset the lower payment made to the agricultural sector. But if the change in the income transfer effect dominates the change in the forest price effect then the agricultural sector lobbies for higher payments. This increases incentives to reduce deforestation, although it is partially offset by the changes to f_β^* and $\partial \pi_\beta/\partial f_\beta^*$.

4.2. SFM sector influence

The same trade-off can also be seen when the SFM sector has influence. Following the same methodology as before, we find:

$$\varphi_\beta = \chi - \left(\frac{(1 + \mu l_\gamma)\frac{\partial w}{\partial f_\beta^*} + (f_t^* + \mu f_\gamma^*)\frac{\partial z}{\partial f_\beta^*} + \frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1 + \mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\mu(F^* - f_\beta)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right) \tag{30}$$

$$\varphi_\gamma = \frac{(1 + \mu l_\gamma)\frac{\partial w}{\partial f_\beta^*} + (f_t^* + \mu f_\gamma^*)\frac{\partial z}{\partial f_\beta^*} + \frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1 + \mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\mu(F^* - f_\beta)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \tag{31}$$

Again, the government factors in the amended indirect effects of the payment scheme: compare (18) and (30) to (19) and (31). Influence from the impact of a change in agricultural forest input demand on agricultural profits is reduced. The government also takes into account the impact of a change in forest input demand in the agricultural sector on the size of the SFM sector. The income

transfer component is modified with the government now concerned about the level of the income transfer to the SFM sector given by $\frac{\mu(F^* - f_\beta^*)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$.

Influence from the SFM sector reduces the importance of the impact of changes in the forest price effect on agricultural profits. This pushes up the level of the payment to agriculture in order to create a greater benefits pie from international REDD finance. The inclusion of the labour demand effect works in the same direction. Yet, the extra focus on the income transfer component to the SFM sector also pushes up the payment to SFM. This reduces the payment to agriculture and incentives to reduce deforestation. Which effect dominates will help determine the direction of change in the payment to either sector.

Our result leads to the unexpected conclusion that, under certain conditions, the SFM sector may lobby for smaller payments to itself in order to increase the size of the benefits pie even though this implies that it obtains a smaller share of the pie. The trade-off faced by the SFM sector is whether to use its influence to increase or reduce its own payment. An increase reduces the incentive to lower deforestation in the agricultural sector and hence, the size of the pie. A decrease strengthens the incentive to lower deforestation thus increasing the size of the pie. The decision is therefore whether to lobby for a greater share of a smaller pie, or a smaller share of a larger pie.

5. Taxes and the labour market

5.1. Input and output taxes

We examine two further policy instruments that a government could implement as part of a national REDD strategy: input and output taxes. Both are lump sum, levied on, respectively, forest use and the produced good in the agricultural sector. Revenues from these taxes are recycled to the whole population on a per-capita basis. Thus, taxes in our model represent a fully equitable per-capita form of benefit sharing. In contrast to payments, there is a separation between incentives and income transfers. Input taxes operate in a similar fashion to the payment scheme in that they drive a wedge between forest input prices in the agricultural and SFM sectors. However, they differ in that they provide equal per-capita revenues rather than the differentiated income transfers observed in the payment scheme.

Applying input taxes shows that similar general equilibrium impacts are taken into account by the government when determining how much of the international incentive is passed through to landowners.[18] Since the government does not factor the income transfer component of the payment scheme into its decisions, the payment scheme and the input tax are equivalent when there is no political influence. This is due to our assumptions of homogenous consumers and a government that only optimises aggregate social welfare.

The output tax has effects similar to those of the other two instruments. It increases with the international incentive, scaled by the impact of output upon the forest input. The impact on profits in the two sectors is taken into account, along with a term representing the impact on revenues from the output tax. The output tax shows a conceptual similarity to both the input tax and the payments scheme. How much of the international incentive reaches landowners again depends on the size of the general equilibrium effects.

When we consider political influence on taxes we see clear directions of change. The ambiguity found with a payment scheme is absent as the income transfer effect is removed. Since taxes only work on forest prices, the inter-linked income transfer component observed when payments are made is no longer present.

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[18] This finding supports the discussion of the payments scheme as 'input tax' plus income transfers. Formal derivations of all results presented in this section are available in Appendix 1.

5.2. Labour market constraints

The presence of perfect labour markets in our model is a strong assumption that is unlikely to hold in many of the jurisdictions in which REDD is, and might potentially be, implemented. When there is no political influence, relaxing this assumption has two main effects.[19]

First, when labour markets are perfectly rigid, workers are confined to their individual labour markets. Any changes in demand for labour are realised in terms of changes in wage rates rather than in movements of labour between sectors. Wages become differentiated among sectors. When there is no political influence, these differential wage effects are included alongside other general equilibrium effects. The changes in wage rates in both forest-using sectors are factored in, weighted by the size of the workforce in each sector. Whether the inclusion of these wage rates increases or lowers incentive levels depends on the relative balance of the change in wage rates in the two sectors. If the wage effect is stronger in the agricultural sector than in the SFM sector payment rates to the agricultural sector will fall, and vice versa.

The second effect emanates from any changes in the scale of derivatives now that the labour input to each of the sectors is fixed. Given the fixed nature of the labour supply, the change in profit levels, and forest use from a change in output levels, may change. Forest use may be more 'sticky' as landowners are unable to hire more labour to substitute for forest. In this case, all the policy instruments will tend to be set at a lower level, implying that less of the international incentive is passed on to the agricultural sector.

6. Discussion and conclusion

In this paper, we developed a model in order to examine the general equilibrium effects of policies implemented for REDD, and investigate how these might change when there is political influence. Such effects help shape the distribution of the costs and benefits of REDD between the two forest-using sectors, agriculture and SFM, which represent an extractive and non-extractive sector, respectively. If these effects are not factored into policy design, then the incentives to reduce extractive forest use (and the associated carbon externalities) could be different from those transferred at the international level to the government.

An efficient REDD policy chosen by a social welfare maximising government is one which factors in general equilibrium effects – relating both to REDD's impact on economic variables via changes in relative prices (the forest price effect) and from its role in distributing benefits (the income transfer effect). This, we find, could raise the marginal cost of the policy. Hence, the full value of the international incentive may not be fully passed through to the relevant sectors if the policies chosen and implemented for REDD have negative economic consequences. Higher international payments would be required to meet an equivalent level of emissions reductions. Accounting for general equilibrium effects therefore implies a move away from the marginal abatement cost concept commonly used to understand and estimate the potential policy costs of REDD. The Stern Review (2006) was the first to make a case for REDD's cost-effectiveness based on this concept. Since then, various analyses have been published, which have come to similar conclusions (see Lubowski and Rose, 2013). Our results imply that once we consider the broader economic impacts of REDD, the overall costs of a given REDD policy are likely to rise.

Policies implemented as part of a national-level REDD strategy are likely to have effects beyond forest-extractive sectors such as certain types of agricultural production. They have the potential to shift landowners between types of forest use, between sectors, and even out of forest-using activities altogether. These shifts are likely to induce changes in output and input prices that may affect the wider economy and either reinforce or weaken the effectiveness of the strategy. An important insight of the model is that even in the absence of incentives to the SFM sector, this sector could still be incentivised to expand as a consequence of incentives made to the agricultural sector to reduce carbon dioxide

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[19] Formal derivation of the results from relaxing the labour market assumption is available in Appendix 2.

emissions from deforestation. Forest shifting from agriculture into joint production results in climate benefits, which are not directly rewarded in our framework.

A key initial assumption of our model is that the government chooses the socially welfare maximising payment rate. We examine a scenario in which one or the other forest-using sector may lobby the government to move away from this rate and find that general equilibrium effects remain important. Application of the common-agency model to this type of policy instrument, which has the capacity to change relative prices and enact unequal income transfers, is shown to have ambiguous effects irrespective of whether the agricultural or SFM sector has influence. In the former, forest price effects lead to the agricultural sector preferring lower payment levels. Income transfer effects work in the opposite direction. The balance between the two types of effect will depend on the scale of the emissions baseline used for REDD, and the degree of dependence on forest for production. Which effect dominates in a given setting is thus an empirical question. For example, data on land uses, production, and prices on inputs and outputs could be utilised in order to help determine the responsiveness of the agricultural sector to changes in the price of forest land, along with the responsiveness of economic factors such as wages and profits to changes in the amount of forest input used in each sector. However such data regarding the substitutability of the different factors of production are often unavailable or difficult to obtain. While national-level REDD strategies are still at an early stage, qualitative data on the political processes associated with REDD are being collected via projects such as CIFOR's Global Comparative Study on REDD+.[20] Such data could provide benchmark data for estimates of the relative influence of different sectors upon the political processes associated with REDD, which would allow us to calibrate some of the model parameters.

With an input or output tax, we see more clearly determined effects. Faced with higher forest or agricultural output prices, an agricultural sector with political influence will use it to ensure that tax rates are reduced. When the SFM sector has influence, it ensures that taxes increase. This determinacy is due to tax incentives being set by the government independently of how it distributes REDD finance. In our model, tax revenues are assumed to be distributed on an equal per-capita basis, and could include public good provision, such as investments in healthcare that may offer broader development benefits.[21] While an oversimplification, the model illustrates how different policies can offer similar incentives to reduce deforestation but differ in how the benefits are shared. We treat the incentive properties of taxes and payments as analogous in our model as they impact relative prices in the same way. In reality, of course, these instruments have different properties, which could be explored and incorporated in a future extension of our model.

Our results suggest that taxes have the potential to be both efficient and equitable. In principle, REDD funded through taxes on land use could be financially self-sustaining. This suggests that at the national scale at least, there would be little need for international finance. While taxes have been utilised to help finance national-scale PES schemes, they are often either general or on goods and services, e.g. the fuel tax to fund the PSA in Costa Rica (Pagiola, 2008). Thus, they do not serve to create the incentives to change land-use as conceptualised in our model. Yet, all that is required in order for governments to introduce a non-zero rate of taxation in our model is an incentive from the international community, financial or otherwise. The focus to date has been on securing finance for domestic REDD strategies and policies from international sources. However, this incentive could be reputational, for example, associated with meeting international commitments such as those related to climate policy.

We show that when incentives change the distribution of benefits between sectors change. In other words, moving towards more socially efficient incentives for reducing emissions from deforestation could change the distribution of REDD benefits. Creating stronger incentives shifts benefits from one sector to another even though the sector that gains fewer benefits in relative terms could gain in absolute terms if the overall pie from REDD is increased. In such cases, increased efficiency would be traded off for less equity in benefit sharing, although all parties would gain from implementing REDD. Indeed,

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[20] See http://www1.cifor.org/gcs/global-comparative-study-on-redd.html.
[21] As long as the provision of public goods offers equal benefits to all individuals and does not affect the production decision such provision has no impact on our model.

REDD stakeholders could, depending on the scale of income and price effects, either lobby for lower or higher payments. Our results therefore suggest that payment schemes, which explicitly link incentives to income transfers, are likely to have those incentives distorted by lobbying behaviour. Should payment schemes be designed with a separation between the incentive and income transfer components then, as under taxes, lobbying would occur in certain directions. While lobbying in our model is restricted to the incentive to deforest, we note that lobbying by either sector might instead focus on influencing other variables; for instance, lobbying the government to change baseline deforestation levels in order to increase income transfers. Analogous to a BAU scenario, our baseline is simply set at the level of deforestation in the absence of REDD. Future work could examine the incentives for different sectors to lobby national- and international-level actors to influence baseline setting.

The linking of incentives to benefit sharing is plausible. Indeed, national-level incentive payment schemes around the developing world often have multiple objectives, including environmental and poverty alleviation goals. We acknowledge, however, that our model oversimplifies the link between the goal to achieve efficient and effective REDD, on one hand, and equitable REDD on the other. Also, our results derive from assumptions about how the benefits from REDD are shared. Future theoretical work could explore how sensitive our results are to changes in these assumptions.

The model developed in this paper is an attempt to address some of the real-world, policy design and implementation issues that have surfaced in previous research undertaken on REDD. It is, however, only a starting point for understanding the broader, economy-wide effects of implementing REDD at the national level, and how political influence might change these. Our attention is focused on two stylised forest-using sectors, and the impacts that REDD policy may have on driving inputs and production between them. The results are robust to the relaxation of perfect labour markets. But the assumption of perfect forest markets is more fundamental to our model. This assumption is unrealistic when applied to the majority of REDD settings. A key extension to the model would be to relax this assumption, and incorporate a more realistic framework for allocating forest resources between sectors. Another limitation is the model's static framework. A dynamic extension of our framework would enable us to model land-use transitions more appropriately as well as allowing for factors such as output prices and wages to be endogenously determined.

Acknowledgments

Appendix 1. Derivation of results for input and output taxes

A.1. Input taxes

Input taxes, r, are levied on forest input so that: $z_\beta = \bar{z} + r$
All revenues are recycled on a per-capita basis.
Welfare becomes:

$$W = w + z f_t^* + \pi_\beta + \pi_\gamma + r f_\beta^* + \chi(F^* - f_\beta^*)$$

Input taxes, r, are derived as:

$$r = \chi - \left(\frac{\partial w}{\partial f_\beta^*} + \frac{\partial z}{\partial f_\beta^*} f_t^* + \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial r}} \right)$$

We assume:

$$\frac{\partial f_\beta^*}{\partial r} < 0, \quad \frac{\partial \pi_\beta}{\partial r} < 0, \quad \frac{\partial \pi_\gamma}{\partial r} > 0, \quad \frac{\partial l_\gamma}{\partial r} > 0, \quad \frac{\partial l_\beta}{\partial r} < 0, \quad \frac{\partial^2 \pi_\beta}{\partial r^2} < 0, \quad \frac{\partial w}{\partial r} < 0$$

Under agricultural influence welfare of the agricultural sector becomes:

$$W_\beta = wl_\beta + zf_\beta^* + \pi_\beta + l_\beta(rf_\beta^* + \chi(F^* - f_\beta^*))$$

With the first differential of:

$$\frac{\partial W_\beta}{\partial r} = \frac{\partial w}{\partial r}l_\beta + \frac{\partial l_\beta}{\partial r}w + \frac{\partial f_\beta^*}{\partial r}z + \frac{\partial z}{\partial r}f_\beta^* + \frac{\partial \pi_\beta}{\partial r} + \frac{\partial l_\beta}{\partial r}(rf_\beta^* + \chi(F^* - f_\beta^*)) + l_\beta\left(f_\beta^* + r\frac{\partial f_\beta^*}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\chi\right)$$

The first order condition is thus:

$$0 = \frac{\partial w}{\partial r} + \frac{\partial z}{\partial r}f_t^* + \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} + f_\beta^* + \frac{\partial f_\beta^*}{\partial r}r - \frac{\partial f_\beta^*}{\partial r}\chi$$

$$+ \mu\left(\frac{\partial w}{\partial r}l_\beta + \frac{\partial l_\beta}{\partial r}w + \frac{\partial f_\beta^*}{\partial r}z + \frac{\partial z}{\partial r}f_\beta^* + \frac{\partial \pi_\beta}{\partial r} + \frac{\partial l_\beta}{\partial r}(rf_\beta^* + \chi(F^* - f_\beta^*)) + l_\beta\left(f_\beta^* + r\frac{\partial f_\beta^*}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\chi\right)\right)$$

Yielding an input tax of:

$$r = \frac{\chi\left(\frac{\partial f_\beta^*}{\partial r}(1 + \mu l_\beta) - \frac{\partial l_\beta}{\partial r}\mu(F^* - f_\beta^*)\right) - \frac{\partial \pi_\beta}{\partial r}(1 + \mu) - \frac{\partial \pi_\gamma}{\partial r} - f_\beta^*(1 + \mu l_\beta)}{\left(\frac{\partial f_\beta^*}{\partial r}(1 + \mu l_\beta) + \mu\frac{\partial l_\beta}{\partial r}f_\beta^*\right)} - \mu\frac{\left(\frac{\partial l_\beta}{\partial r}w + \frac{\partial f_\beta^*}{\partial r}z\right) - (1 + \mu l_\beta)\frac{\partial w}{\partial r} - (f_t^* + \mu f_\beta^*)\frac{\partial z}{\partial r}}{\left(\frac{\partial f_\beta^*}{\partial r}(1 + \mu l_\beta) + \mu\frac{\partial l_\beta}{\partial r}f_\beta^*\right)} \text{(A7)}$$

Under SFM influence welfare of the SFM sector is:

$$W_\gamma = wl_\gamma + zf_\gamma^* + \pi_\gamma + l_\gamma(rf_\beta^* + \chi(F^* - f_\beta^*))$$

Giving a first differential of:

$$\frac{\partial W_\gamma}{\partial r} = \frac{\partial w}{\partial r}l_\gamma + \frac{\partial l_\gamma}{\partial r}w + \frac{\partial f_\gamma^*}{\partial r}z + \frac{\partial z}{\partial r}f_\gamma^* + \frac{\partial \pi_\gamma}{\partial r} + \frac{\partial l_\gamma}{\partial r}(rf_\beta^* + \chi(F^* - f_\beta^*)) + l_\gamma\left(f_\beta^* + r\frac{\partial f_\beta^*}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\chi\right)$$

This yields a first order condition of:

$$0 = \frac{\partial w}{\partial r} + \frac{\partial z}{\partial r}f_t^* + \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} + f_\beta^* + \frac{\partial f_\beta^*}{\partial r}r - \frac{\partial f_\beta^*}{\partial r}\chi$$

$$+ \mu\left(\frac{\partial w}{\partial r}l_\gamma + \frac{\partial l_\gamma}{\partial r}w + \frac{\partial f_\gamma^*}{\partial r}z + \frac{\partial z}{\partial r}f_\gamma^* + \frac{\partial \pi_\gamma}{\partial r} + \frac{\partial l_\gamma}{\partial r}(rf_\beta^* + \chi(F^* - f_\beta^*)) + l_\gamma\left(f_\beta^* + r\frac{\partial f_\beta^*}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\chi\right)\right)$$

Yielding an input tax of:

$$r = \frac{\chi\left(\frac{\partial f_\beta^*}{\partial r} - \mu\frac{\partial l_\gamma}{\partial r}(F^* - f_\beta^*) + \mu l_\gamma\frac{\partial f_\beta^*}{\partial r}\right) - \frac{\partial \pi_\beta}{\partial r} - \frac{\partial \pi_\gamma}{\partial r}(1 + \mu) - f_\beta^*(1 + \mu l_\gamma) - \mu\left(\frac{\partial l_\gamma}{\partial r}w + \frac{\partial f_\gamma^*}{\partial r}z\right) - (1 + \mu l_\gamma)\frac{\partial w}{\partial r} - (f_t^* + \mu f_\gamma^*)\frac{\partial z}{\partial r}}{\frac{\partial f_\beta^*}{\partial r}(1 + \mu l_\gamma) + \mu\frac{\partial \gamma}{\partial r}f_\beta^*}$$

A.2. Output tax

An ad-valorem tax, *t*, is levied output so that:

$$p_\beta = p_\beta^* + t$$

with again revenues redistributed on a per-capita basis.

We assume:

$$\frac{\partial f_\beta^*}{\partial t} < 0, \quad \frac{\partial \pi_\beta}{\partial t} < 0, \quad \frac{\partial \pi_\gamma}{\partial t} > 0, \quad \frac{\partial y_\beta^*}{\partial t} < 0, \quad \frac{\partial l_\gamma}{\partial t} > 0, \quad \frac{\partial l_\beta}{\partial t} < 0, \quad \frac{\partial^2 \pi_\beta}{\partial t^2} < 0, \quad \frac{\partial w}{\partial t} < 0$$

Total social welfare becomes:

$$W = w + z f_t^* + \pi_\beta + \pi_\gamma + t y_\beta^* + \chi (F^* - f_\beta^*)$$

Output taxes are derived as:

$$t = \chi \frac{\partial f_\beta^*}{\partial y_\beta^*} - \frac{\partial w}{\partial f_\beta^*} - \frac{\partial z}{\partial f_\beta^*} f_t^* - \frac{\partial \pi_\beta}{\partial y_\beta^*} - \frac{\partial \pi_\gamma}{\partial y_\beta^*} - \frac{y_\beta^*}{\frac{\partial y_\beta^*}{\partial t}}$$

Under agricultural influence agricultural sector welfare is:

$$W_\beta = w l_\beta + z f_\beta^* + \pi_\beta + l_\beta (t y_\beta^* + \chi (F^* - f_\beta^*))$$

This gives a first differential of:

$$\frac{\partial W_\beta}{\partial t} = \frac{\partial w}{\partial t} l_\beta + \frac{\partial l_\beta}{\partial t} w + \frac{\partial f_\beta^*}{\partial t} z + \frac{\partial z}{\partial t} f_\beta^* + \frac{\partial \pi_\beta}{\partial t} + \frac{\partial l_\beta}{\partial t} (t y_\beta^* + \chi (F^* - f_\beta^*)) + l_\beta \left(y_\beta^* + t \frac{\partial y_\beta^*}{\partial t} - \frac{\partial f_\beta^*}{\partial t} \chi \right)$$

This yields a first order condition of:

$$0 = \frac{\partial w}{\partial t} + \frac{\partial z}{\partial t} f_t^* + \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} + y_\beta^* + \frac{\partial y_\beta^*}{\partial t} t - \frac{\partial f_\beta^*}{\partial t} \chi$$

$$+ \mu \left(\frac{\partial w}{\partial t} l_\beta + \frac{\partial l_\beta}{\partial t} w + \frac{\partial f_\beta^*}{\partial t} z + \frac{\partial z}{\partial t} f_\beta^* + \frac{\partial \pi_\beta}{\partial t} + \frac{\partial l_\beta}{\partial t} (t y_\beta^* + \chi (F^* - f_\beta^*)) + l_\beta \left(y_\beta^* + t \frac{\partial y_\beta^*}{\partial t} - \frac{\partial f_\beta^*}{\partial t} \chi \right) \right)$$

The output tax is therefore:

$$t = \frac{\chi \left(\frac{\partial f_\beta^*}{\partial t} (1 + \mu l_\beta) - \frac{\partial l_\beta}{\partial t} \mu (F^* - f_\beta^*) \right) - \frac{\partial \pi_\beta}{\partial t} (1 + \mu) - \frac{\partial \pi_\gamma}{\partial t} - y_\beta^* (1 + \mu l_\beta) - \mu \left(\frac{\partial l_\beta}{\partial t} w + \frac{\partial f_\beta^*}{\partial t} z \right) - (1 + \mu l_\beta) \frac{\partial w}{\partial t} - (f_t^* + \mu f_\beta^*) \frac{\partial z}{\partial t}}{\frac{\partial y_\beta^*}{\partial t} (1 + \mu l_\beta) + \frac{\partial l_\beta}{\partial t} \mu y_\beta^*}$$

Under SFM influence the welfare of the SFM sector is:

$$W_\gamma = w l_\gamma + z f_\gamma^* + \pi_\gamma + l_\gamma (t y_\beta^* + \chi (F^* - f_\beta^*))$$

This gives a first differential of:

$$\frac{\partial W_\gamma}{\partial t} = \frac{\partial w}{\partial t} l_\gamma + \frac{\partial l_\gamma}{\partial t} w + \frac{\partial f_\gamma^*}{\partial t} z + \frac{\partial z}{\partial t} f_\gamma^* + \frac{\partial \pi_\gamma}{\partial t} + \frac{\partial l_\gamma}{\partial t} (t y_\beta^* + \chi (F^* - f_\beta^*)) + l_\gamma \left(y_\beta^* + t \frac{\partial y_\beta^*}{\partial t} - \frac{\partial f_\beta^*}{\partial t} \chi \right)$$

The first order condition is therefore:

$$0 = \frac{\partial w}{\partial t} + \frac{\partial z}{\partial t} f_t^* + \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} + y_\beta^* + \frac{\partial y_\beta^*}{\partial t} t - \frac{\partial f_\beta^*}{\partial t} \chi$$

$$+ \mu \left(\frac{\partial w}{\partial t} l_\gamma + \frac{\partial \gamma}{\partial t} w + \frac{\partial f_\gamma^*}{\partial t} z + \frac{\partial z}{\partial t} f_\gamma^* + \frac{\partial \pi_\gamma}{\partial t} + \frac{\partial l_\gamma}{\partial t} (t y_\beta^* + \chi (F^* - f_\beta^*)) + \gamma \left(y_\beta^* + t \frac{\partial y_\beta^*}{\partial t} - \frac{\partial f_\beta^*}{\partial t} \chi \right) \right)$$

The output tax is therefore:

$$t = \frac{\chi\left(\frac{\partial \pi_\beta^*}{\partial t}(1+\mu l_\gamma) - \frac{\partial l_\gamma}{\partial t}\mu(F^* - f_\beta^*)\right) - \frac{\partial \pi_\beta}{\partial t} - \frac{\partial \pi_\gamma}{\partial t}(1+\mu) - y_\beta^*(1+\mu l_\gamma) - \mu\left(\frac{\partial l_\gamma}{\partial t}w + \frac{\partial f_\gamma^*}{\partial t}z\right) - (1+\mu l_\gamma)\frac{\partial w}{\partial t} - (f_t^* + \mu f_\gamma^*)\frac{\partial z}{\partial t}}{\frac{\partial y_\beta^*}{\partial t}(1+\mu l_\gamma) + \frac{\partial \gamma}{\partial t}\mu y_\beta^*}$$

Appendix 2. Derivation of results under labour market constraints

When labour markets are perfectly sticky wages, w, in the three different sectors are not equalised and thus overall social welfare includes the labour income from the three sectors.

$$W = w_\alpha l_\alpha + w_\beta l_\beta + w_\gamma l_\gamma + z f_t^* + \pi_\beta' + \pi_\gamma' + CS + \lambda(\varphi_\beta + \varphi_\gamma - \chi)$$

Following the same steps as for when labour markets are free the payment levels can be derived:

$$\varphi_\beta = \chi - \left(\frac{\partial w_\beta}{\partial f_\beta^*}l_\beta + \frac{\partial w_\gamma}{\partial f_\beta^*}l_\gamma + \frac{\partial z}{\partial f_\beta^*}f_t^* + \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right)$$

$$\varphi_\gamma = \frac{\partial w_\beta}{\partial f_\beta^*}l_\beta + \frac{\partial w_\gamma}{\partial f_\beta^*}l_\gamma + \frac{\partial z}{\partial f_\beta^*}f_t^* + \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$$

Under agricultural sector influence the welfare of the agricultural sector is amended to include the differential wage rate, becoming: $W_\beta = w_\beta l_\beta + z f_\beta^* + \pi_\beta + \varphi_\beta F^*$

This gives a first-order differential of: $\frac{\partial W_\beta}{\partial \varphi_\beta} = \frac{\partial w_\beta}{\partial \varphi_\beta}l_\beta + \frac{\partial z}{\partial \varphi_\beta}f_\beta^* + \frac{\partial f_\beta^*}{\partial \varphi_\beta}z + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^*$

Yielding a payment rate of: $\varphi_\beta = \chi - \left(\frac{\partial w_\beta}{\partial f_\beta^*}l_\beta(1+\mu) + \frac{\partial w_\gamma}{\partial f_\beta^*}l_\gamma + \frac{\partial z}{\partial f_\beta^*}(f_t^* + \mu f_\beta^*) + \frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \mu z + \frac{\mu F^* + f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right)$

Under SFM influence the welfare of the SFM sector is:
$W_\gamma = w_\gamma l_\gamma + z f_\gamma^* + \pi_\gamma + \varphi_\gamma(F^* - f_\beta^*)$
Following the same steps this gives the payment rate of:
$$\varphi_\beta = \chi - \left(\frac{(1+\mu l_\gamma)\frac{\partial w_\gamma}{\partial f_\beta^*} + (f_t^* + \mu f_\gamma^*)\frac{\partial z}{\partial f_\beta^*} + \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial w_\beta}{\partial f_\beta^*}l_\beta}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\mu(F^* - f_\beta)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right)$$

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