Modelling political influence on the choice of policies for REDD+

Abstract

Reducing Emissions from Deforestation and forest Degradation has recently returned to the spotlight in international climate change negotiations. Through a general equilibrium framework we examine the factors that influence the level and distribution of costs and benefits among sectors from the implementation of various policies, for a country facing an incentive to institute a national REDD+ strategy. We extend the general equilibrium framework in order to explore the implications of sectoral political influence on the scale and distribution of different REDD+ policy instruments. We find that the government factors in the general equilibrium effects of the policy along with the size of the incentive when determining the levels of policy. These general equilibrium effects help to determine the level of REDD+ effort undertaken by the government, and the distribution of returns and effort between sectors. When there is influence on the government we find indeterminate and counter-intuitive results under a direct payments policy. Sectors may lobby for a lower rate of payments to its own sector in order to create a stronger incentive to reduce forest use in the other sector and boost the level of international payment.

1. Introduction

Reducing emissions from deforestation and forest degradation (REDD+) has emerged as an important policy tool for reducing anthropogenic greenhouse gas emissions. The sector contributes between 10 and 20% of annual totals and has been identified as a potential low-cost option for reducing emissions (van der Werf et al., 2009). The question is increasingly becoming how countries should best utilise finance available for REDD+ – what policy instruments should be used to reduce deforestation emissions?

Although there is still work to be done regarding the final design structure of any REDD+ mechanism under the United Nations Framework Convention on Climate Change (UNFCCC) certain patterns are emerging. One of the most crucial of these is the basing of REDD+ structures at national levels. National governments are likely to have responsibility for setting baselines against which any payments might be made, harnessing finance, and implementing or approving policies and projects. This trend has led to the formation of national level REDD+ strategies in many countries, notably through the work of the Forest Carbon Partnership Facility. An example of such a national-level REDD+ strategy is Guyana's Low Carbon Development Strategy, which harnesses REDD+ finance from Norway to implement economy-wide projects and policies.

Guyana's experience highlights another important emerging trend: that of bilateral agreements. Norway has concluded deals with Guyana, Brazil and Indonesia offering finance in exchange for reductions in deforestation levels- with the final decision-making regarding use of the finance resting with the recipients. These bilateral agreements are based upon finance provided for reductions in the carbon emissions from deforestation below some pre-determined baseline. They can be thought of as a tool for addressing the carbon externality that can arise from the extractive use of the forest and internalising, and thus promoting a reduction in, a negative externality that would result from destruction of the forest, and the associated greenhouse gas emissions. Alternatively they can be thought of as rewarding the promotion of positive externalities that result from reducing deforestation below some business as usual scenario – or indeed from undertaking replanting and restoration exercises to promote the sequestration of carbon from the atmosphere.

The difference between the two viewpoints depends on what baseline is used for REDD+. If we set the baseline where there is no deforestation then we can think of REDD+ as penalising every tonne of negative externality. If on the other hand we conceive as the baseline as a business-as-usual then REDD+ will be rewarding every ton of positive externality created from reducing below this level.[1] In this paper the conceptualisation is more towards the latter, where government are effectively rewarded for reducing deforestation on a per unit basis below a baseline – this is more closely based on the bilateral agreements arising across the world.

The incentive received by the government may not be all financial, it could be reputational or political, witness the adoption of voluntary targets for reducing deforestation in Brazil and Indonesia, with associated reputations both at home and abroad wrapped up in them. Although we focus on a financial incentive in this paper the model may still provide insight in the case of an incentive in terms of reputation.

REDD Policies

Angelsen et al., (2009) categorises policies for REDD+ falling into four main areas: policies that reduce the rent from forest-extractive industries, policies to increase and capture the rents from using forests sustainably, policies that directly regulate land-use and cross-sectoral policies. These policies all have impacts beyond that of the sectors directly affected. By shifting labour, capital and other inputs between sectors – via shifts in relative prices – there may be wider economic impacts from REDD+. By encouraging the growth of sectors other than the forest-extractive industries, input and output prices and the relative profitability of sectors may all be impacted.

These effects may be crucial in understanding how governments make decisions regarding the strength of REDD+ policy and how the costs and benefits are shared between different sectors. The effects motivate using a general equilibrium setting to investigate questions regarding REDD+ policy. Such a general equilibrium setting captures a policy's impact on factor and output prices and the subsequent effects on the economy as a whole for producers and consumers - moving the analysis beyond the specific sector in question.

To date the majority of literature regarding policy choice for reducing deforestation has focused on partial equilibrium approaches. Ferraro & Simpson (2002) compare direct and indirect conservation payments, while Groom & Palmer (2008) investigate the same choice but incorporate missing markets. Muller & Albers (2004) use a simple model to compare policies for forest conservation including enforcement, agricultural development projects and conservation payments. Deacon (1995) provides one of the few examples of analysing these policy options in a general equlibrium setting, looking at the impact of transportation improvements, taxes and employment opportunity enhancement on deforestation.

The options for REDD+ mirror those of forest conservation more generally. Angelsen has written a number of publications outlining the different potential policy options (Angelsen 2008, Angelsen et al. 2009, Angelsen 2010), while Daviet (2009) outlines the potential for

[1] For a more detailed description of the role of baselines see (Angelsen, 2008b)

policies such as fire protection, the reduction of illegal logging and forest restoration. Pfaff et al. (2010) outlines options for both domestic and international policy.

We extend this literature, building a general equilibrium model to look at the balance of policies between sectors chosen by a REDD+ recipient government – identifying general equilibrium factors that help to define REDD+ policy choice. The range of policies we investigate is limited compared to the full range discussed in the literature. We focus on the establishment of a payments scheme which distributes the costs (in terms of an increase in the price of using the forest in an extractive sector) and the benefits between sectors. We also include discussion of taxes, both input and output, and the combination of taxes and payment schemes. These policies allow us to focus upon the general equilibrium effects that result from changes in relative prices. The focus on a small subset of policies is a limitation, but the overall arguments regarding the inclusion of general equilibrium effects in policy choice is valid for a wider basket of policies.

In our model we conceive as the international incentive offered to the government as a 'pie'. The size of this pie and the distribution of it between sectors are dependent on the policy choices made by government. Under taxes we assume that the international incentive pie is added to tax revenue and redistributed on a per-capita basis. This creates a separation between the size of the pie and the share. In contrast under our direct payments scheme the choice of direct payment rate helps to determine both the size and the share. This connection between the size and the share in the direct payment scheme is fundamental to our results.

Beyond the economics of REDD+ policy-choice lie political economy factors that may also help to explain policy choice. REDD+ policy may be more prone to these political economic factors than other realms of policy choice. The natural resource management sectors have long been beset by challenging governance environments, corruption and capture of the political process by lobby groups (Amacher, 2006; Koyuncu & Yilmaz, 2008; Palmer, 2005). It is within this governance environment that REDD+ is being introduced, with the addition of powerful, and growing, influential organisations in the realm of conservation, the environment and indigenous rights. The nature of the overall governance environment of the countries likely to be involved in REDD+ can also be brought into doubt. One must only interlay a map of deforestation rates with that of Transparency International's Corruption Perception Index to see the vulnerability of these countries to corruption.

Modelling

The general equilibrium model that we construct to help to answer questions relating to REDD+ policy choice is extended to bring in political influence from lobby groups. This builds on the seminal work of Helpman & Grossman (1994) who build a common-agency model to investigate the impact of lobby group influence on trade policy. This approach has been followed extensively, notably in the area of environmental taxes and subsidies (Fredriksson, 1997), environmental protection (Schleich 1997) and in the realm of forest conservation (Eerola (2004) all through the formation of common-agency models. Work by Jussila (2003) extends the framework to incorporate the problem to a logging industry in which there is insecure property rights and externalities from standing forests. Yu (2005) builds a model in which lobby groups can have direct or indirect influence on a government making policy relating to environmental protection.

The literature in this area assumes that influence is in the form of 'contributions' paid to the incumbent government- which desires these contributions to aid re-election. However there are no explicit assumptions that require this line of thought to be the only valid one. The ‘contributions’ are essentially a valuation by the government of some element of the welfare change of one specific sector, over the others, in response to a change in policy levels. This valuation may indeed be the monetary one previously discussed, or it may be due to preferences inherent in the government for one sector over another – either due to interest group lobbying, political make-up of the country or perceptions that protection of that particular section offers long-term benefits to the country. With this in mind we perceive the giving of ‘contributions’ more in the vein of having ‘political influence’ thus in this paper we will use the latter term instead of the former.

We construct a model that builds upon Helpman & Grossman (1994), specifically adopting the consumer and producer formulation of Fredriksson (1997) – simplifying the model to three sectors in a similar vein to the model of forest use in Jussila (2003). We provide two important contributions to this strand of literature. We apply this method of policy modelling to a current live international debate regarding country-level policy choices for REDD+ and we also extend the methodology for a policy choice that includes a level of international incentive to address a negative externality – and include the possibility of a policy that both changes relative prices and has unequal income transfers. Previous work in this area has focused on policies that shift the relative prices of inputs or outputs – returning revenue on a per-capita basis. By including an option for a direct payments scheme we include a different type of instrument. Direct payment schemes shift the relative price of inputs – and provide a series of income transfers to different sectors. Indeed these two parts are intrinsically linked in such schemes – with the size of the shift in relative prices helping to determine the level of income transfer. We also investigate the implications of including such schemes alongside more traditional policies focusing on solely changing relative price, in a situation with interest group influence.

Essentially what we create is a general equilibrium model of an economy of three sectors, upon which we impose an international incentive for REDD+, solving the policy choices made by the government. In the first sector, that we term agriculture, forest is substitutable with labour and use of the forest produces a carbon externality. In the other forest-using sector that we call sustainable forestry (SFM), forest is used in joint production with labour and there is no carbon externality. Distribution of a total amount of forest between sectors is determined in a market setting. Agents switch their capital between forest sectors in relation to relative profit levels.

We impose on this model an international incentive, in terms of a payment-per-unit of carbon externality reduced below a business-as-usual baseline. In order to reduce this level the government implements a direct payment scheme. Payments are made to both forest sectors with the total sum equal to the international incentive. The government then faces a choice of the level of payment that should be made to either sector. We find that the government factors in general equilibrium effects of the policy along with the size of the incentive when determining the levels of direct payments. These general equilibrium effects help to determine the level of REDD+ effort undertaken by the government, and the distribution of returns and effort between sectors.

We then examine the case where either the agricultural or SFM sector has political influence. When the agricultural sector has political influence the direction of change in direct payments to either sector is indeterminate. It depends on a ‘price’ effect that represents the adverse impact direct payments have upon the price of forest in that sector and an ‘income’ effect that tends to push up the level of payments to the agricultural sector, as the sector tries to grab a greater share of the 'pie' created by the incentive. Which of these effects dominates depends on factors such as the dependence of the agricultural sector on the forest input, the ease to which agents can switch their activity between sectors and the size of the forest baseline. A similar indeterminate result is seen when the SFM sector has political influence. Again, the balance between the price and the income effect determines the direction of change. This leads to the counter-intuitive result that under some conditions the SFM sector may lobby for a lower rate of payments to its own sector – in order to create a stronger incentive to reduce forest use in the agricultural sector and boost the level of international payment.

These findings are contrasted with a situation where the government implements an input and output tax on the agricultural sector. We see similar general equilibrium effects taken into account when neither sector has influence, but when the agricultural sector has influence we see input tax rates reduced. Tax rates rise when the SFM sector has influence.

In Section 2 we outline the basic model. In Section 3 we apply a REDD+ policy to this model, extending the model to political influence in Section 4. Section 5 discusses extensions to the model, including the use of multiple instruments and the relaxation of some of the assumptions regarding perfect markets. Section 6 concludes.

2. The basic model

The majority of countries likely to be recipients of REDD+ finance can be categorised as small, open economies. Hence for our model we assume a small, open, competitive economy. Within this economy there are three producing sectors, two of which utilise a forest input, f, in their production. The first of these sectors, that we term agriculture, has two main inputs: forest and labour, which are substitutable using a constant-returns-to-scale technology. The sector uses the forest in an extractive fashion, producing a negative carbon externality in the process. We think of this externality as arising from clearing of the forest in order to create land for farming. This sector represents a forest-extractive industry and although we term it agriculture it can be conceived as the main driver of deforestation that may be different in different areas. In Brazil it could best be thought of as soya or beef production; in Indonesia it might be palm oil plantations; in Guyana it could be thought of as mining activity.[2] This sector is represented by β in the nomenclature in this paper – and we term the good that is produced in this sector as x_β.

The second sector, that also uses the forest as an input, we term sustainable forest management (SFM). It uses the forest as input, again in combination with labour, and is categorised by joint production – i.e. labour and forest are strict complements. Use of the forest in this sector does not produce a negative carbon externality. Essentially the sector produces without clearance of the forest. This sector follows similar assumptions regarding joint production as Ferraro & Simpson (2002) – and is broadly representative of a non-extractive forest-using sector – this could be SFM, or eco-tourism, or non-timber forest

[2] We note that these sectors have very different impacts regarding long-term land use and wider environmental issues. However for the nature of our model here they are analogous.

product collection depending on the context.[3] This sector is represented by γ in the nomenclature – and the good that is produced we call x_γ.

The third sector we set-up as a numeraire, in order to represent all other production in the economy. This sector acts as the base for which we calculate all relative prices – and allows us to capture the entire economy. We term this sector industry and assume it uses a single factor, labour, alone using constant returns to scale technology and an input-output coefficient of 1. The good that is produced in this sector we term x_α.

Prices, $p_{i\in\alpha,\beta,\gamma}$ are determined on the world market, and are thus exogenously given. We normalise $p_\alpha$to 1, thus prices in the two production goods sectors are relative prices compared to the numeraire.

The economy is populated by N individuals, each of whom has one unit of labour. We normalise N to 1. Individuals have a number of roles in this model: they sell their own labour endowment to one of the three sectors – when individuals are discussed in this context they are termed workers; they receive profits from one of the three sectors –we call them operators; and they consume goods from all three sectors – and are termed consumers. Individuals are categorised by which sector they receive profits from (and operate in) – either industry, α, agriculture, β or SFM, γ.

Workers can sell their labour endowment to any sector and we assume that there is a large enough supply of labour for x_α to be produced in all cases. Competitive labour market equilibrium implies wages are equated in all sectors – we normalise this equalised wage rate to 1. This assumption of perfect labour markets is a bold one, considering the imperfect nature of markets in many REDD+ finance recipient countries. We discuss the implications of relaxing this assumption on the model in Section 5 below.

In their role as operators we assume that individuals in agriculture and SFM can switch between sectors based on relative profits in that sector. We assume each operator has a different relative profit level at which point they switch between forested sectors – thus switching between sectors occurs as profits in either sector rise or fall. Operators are unable to switch their capital between the industry and the agriculture or SFM sectors. We essentially assume that operators in the forested sectors are fundamentally different from those in industry. This is a strong assumption but can be justified if there is some barrier for those in industry to operate in the forest sector: economic, social, geographical or institutional.

All sectors maximise profits, giving the restricted profit function $\pi_i(p_i, \bar{z})$ where $\bar{z}$ is the price of the forest input, f for the agricultural and SFM sectors.

These two sectors derive optimal output y_i^* as the level of output that solves:

$$p_i = \frac{\partial c_i}{\partial y_i} \; for \; i \in \beta, \gamma$$

[3] Again we note the differences between these activities, however again they can be seen as analogous for our purposes.

where $\frac{\partial c_i}{\partial y_i}$ is the partial differential of the cost function, $c_i(f_i, l_i, \bar{z})$. Given this level of optimal output the sectors then calculate their level of forest demand f_i and labour demand l_i as the solutions to:

$$\min c_i(f_i, l_i, \bar{z})$$

$\bar{z}$ is determined in a forest market determined by the following operation and timeline:

1. Both sectors observe output prices in their sector.
2. Sectors then calculate their level of output, forest demand and labour demand for each level of $\bar{z}$.
3. A third party then calculates the forest input price $\bar{z}$ based on the requirement that:

$$f_\beta^* + f_\gamma^* = f_t^*$$

where f_t^* is the total amount of forest input for use in the economy. This can be thought of as the total forested area opened up for production by the government. This could be the total forest area with protected areas excluded – or could be thought of as the total area of accessible forest. The third party in step 3 is analogous to the concept of a Walrasian auctioneer that acts as an independent party that works to clear the market.

The determination of $\bar{z}$ clears all markets and defines optimal output, y_i^*, realised forest input demands, f_i^*, labour input demands l_i^* and forest input price $\bar{z}$. These in turn determine profit levels in each sector and define the distribution of operators between sectors.

This assumption of perfectly operating forest markets is bold, but justifiable in terms of the aims of our model in analysing the general equilibrium effects, driven by changes in relative prices. The forest market also allows for switching of forest use between sectors, thus capturing the aim of REDD+ policy to incentivise the use of forest to switch from extractive to non-extractive use.

Consumption

Consumers consume all three goods. Utility is an additive function of consumption of the goods, $x_\alpha, x_\beta, x_\gamma$:

$$U_i = x_\alpha^i + x_\beta^i + x_\gamma^i$$

for $i = \alpha, \beta, \gamma$ where x_α^i is consumption of the numeraire and x_β^i , x_γ^i is consumption of each production good.

Consumers are subject to a budget constraint and are assumed to use all income, Y_i, to purchase the two goods.

$$Y_i = x_\alpha^i + p_\beta^*.x_\beta^i + p_\gamma^*.x_\gamma^i$$

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 numeraire price.

From the above an indirect utility function, V_i, can be derived:

$$V_i = Y_i + u\left(d_\beta(p_\beta^*)\right) - p_\beta^* d_\beta(p_\beta^*) + u\left(d_\gamma(p_\gamma^*)\right) - p_\gamma^* d_\gamma(p_\gamma^*)$$

where $d_\beta(p_\beta^*), d_\gamma(p_\gamma^*)$ are the realisations of the demand function for consumers (who we assume to have identical preferences) 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 therefore represent consumer surplus from consumption of the production goods. Given that world market prices are exogenously determined on the international market the values for consumer surplus is fixed and utility is thus a direct function of income.[4]

Income

Income in the agricultural sector comes from two sources, labour income and profits from the production of x_β. The income of all individuals in the sector is thus:

$$Y_\beta = \beta + \pi_\beta$$

where β is the share of population who operate in that sector and represents labour income.

The SFM sector follows the same model with total income for the sector

$$Y_\gamma = \gamma + \pi_\gamma$$

where γ is the share of population who operate in that sector.

For operators in the industry sector again income comes from labour income and profits

$$Y_\alpha = \alpha + \pi_\alpha$$

where α is the share of population who operate in that sector. π_α is a constant that is not impacted by any of the changes in our model and is thus we drop it from the remainder of our model.

Social welfare, W, is given by the aggregate indirect utility of the population which follows from above as:

$$W = 1 + \pi_\beta + \pi_\gamma + u\left(d_\beta(p_\beta^*)\right) - p_\beta^* d_\beta(p_\beta^*) + u\left(d_\gamma(p_\gamma^*)\right) - p_\gamma^* d_\gamma(p_\gamma^*)$$

We assume that the use of each unit of forest input used in agriculture, f_β, creates one unit of the carbon externality – and $F^* = f_\beta^*$ is the level of forest-based carbon externality in the base case of the model. This essentially gives us the baseline before the enactment of any REDD+ policy and can be thought of us a business-as-usual scenario of carbon emissions from deforestation below which a government is incentivised to reduce deforestation and its associated carbon emissions.

3. Introducing REDD+

We now look at the effect of the enactment of a REDD+ agreement that offers the government of the economy (henceforth - the government) an incentive χ for reduction in the creation of the forest-related externality below the baseline level, F^*, with $\chi > 0$ and payments of zero for $f_\beta^* > F^*$. This follows the types of bilateral agreements that are emerging around the world, discussed above – and follows the conceptualisation of a future REDD+ agreement under the UNFCCC.

As discussed in Section 1 we restrict the suite of policies available to the government to reduce deforestation to: an output tax, an input tax or a direct payments scheme.

[4] This follows closely similar assumptions made in Fredriksson (1997).

Payments Scheme
We first assume that the government implements a direct payment scheme with some level of payments to the agricultural and SFM sectors. We assume the payment scheme gives a payment, ρ, to each forest sector of:

$$\rho_i = \varphi_i\left(F^* - f_\beta^*\right)\ i \in \beta, \gamma$$

with $\chi = \sum_{i=\beta,\gamma} \varphi_i$ and $\varphi_i > 0$. It is assumed that payments accrue to operators in the agricultural sector.[5]

The payment scheme essentially splits the entire pie from the international incentive between the two sectors – and as the size of the pie is dependent on the activity of the agricultural sector it serves to increase the price of forest input in this sector. Effectively the direct payment scheme consists of two parts – an income transfer component equal to the rate of direct payment multiplied by the baseline forest use, F^* and an increase in the price of utilising the forest input faced by the agricultural sector. In the SFM sector the direct payments scheme just equates to an income transfer equal to the rate of direct payment to that sector multiplied by the reduction in the carbon externality. Thus the direct payment scheme has the effect of driving a wedge in forest input prices between the two sectors. In this way the direct payment scheme can be conceived of as a tax on forest input in the agricultural sector with the tax revenues, plus the international incentive returned at an unequal rate between the agricultural and SFM sectors.

The direct payment scheme conceptualised here effectively provides a positive incentive to reduce the carbon externality in the agricultural sector – and splits the proceeds between the two forested sectors. It offers a payment from refraining from an activity, rather than a subsidy for undertaking an alternative.

With the direct payments scheme the profit function for agriculture is amended to:

$$\pi'_\beta = \pi_\beta[p_\beta^*, \bar{z} + \varphi_\beta] + \varphi_\beta F^*$$

The profit function for SFM becomes:

$$\pi'_\gamma = \pi_\gamma[p_\gamma^*, \bar{z}] + \varphi_\gamma(F^* - f_\beta^*)$$

Overall social welfare becomes:

$$W = 1 + \pi'_\beta + \pi'_\gamma + u\left(d_\beta\left(p_\beta^*\right)\right) - p_\beta^* d_\beta\left(p_\beta^*\right) + u\left(d_\gamma\left(p_\gamma^*\right)\right) - p_\gamma^* d_\gamma\left(p_\gamma^*\right)$$

The government's maximisation problem is thus:

$$\max_{\varphi_\beta, \varphi_\gamma} W = 1 + \pi'_\beta\left[p_\beta, \bar{z}, \varphi_\beta\right] + \pi'_\gamma\left[p_\gamma, \bar{z}, \varphi_\gamma, f_\beta^*\right] + CS$$

Subject to:

- $\sum_{i=\beta,\gamma} \varphi_i = \chi$

[5] Should payments be given to consumers in β after the production decision is made there will be no effect on levels of forest input.

where CS is the constant level of consumer surplus relating to the two production goods.[6]

$$CS = u\left(d_\beta(p_\beta^*)\right) - p_\beta^* d_\beta(p_\beta^*) + u\left(d_\gamma(p_\gamma^*)\right) - p_\gamma^* d_\gamma(p_\gamma^*)$$

We solve the maximisation problem using the Lagrangian method with the government maximising:

$$W = 1 + \pi'_\beta[p_\beta, \bar{z}, \varphi_\beta, f_\beta^*] + \pi'_\gamma[p_\gamma, \bar{z}, \varphi_\gamma, f_\beta^*] + CS$$
$$+\lambda(\varphi_\beta + \varphi_\gamma - \chi)$$

This gives the first order conditions of:

$$\frac{\partial W}{\partial \varphi_\beta} = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f_\beta^*}{\partial \varphi_\beta} + \lambda$$

$$\frac{\partial W}{\partial \varphi_\gamma} = (F^* - f_\beta^*) + \lambda$$

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

Solving these conditions gives the following solutions to the level of direct payments:

$$\varphi_\beta = \chi - \left(\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right) (1)$$

$$\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \ (2)$$

$$\lambda = -(F^* - f_\beta^*)$$

with the constraints of:

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

Essentially the bracketed term in (1) – and the payment made to the SFM sector (2) – represents the general equilibrium effects of the direct payment scheme.

The amount of the incentive transferred to agriculture is equal to the international payment minus the general equilibrium impacts of the implementing the direct payment scheme. These general equilibrium effects are the impact of changing the level of forest input in agriculture on profits in both the agriculture and SFM sectors, and a final term that results from the similarity between the direct payments scheme and an input tax.

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

We could conceive the direct payment scheme as consisting of a fixed level of income transfer – dependent on the baseline forest level – and an input tax levied on the agricultural sector – at the rate of the direct payment to that sector. The revenues are redistributed according to the rate of payment to the agricultural and SFM sectors.

The last term in (1) can be then be thought of as the 'revenue' implications of changing the price of forest input through the direct payments to agriculture. It includes both elements of the size of the 'revenue base' (f_β^*), and the change in the 'revenue base' from the change in the payment rate ($\frac{\partial f_\beta^*}{\partial \varphi_\beta}$).

The factoring in by the government of these general equilibrium effects of the direct payments scheme may imply that a different level of incentive is transferred down to producers from the introduction of a REDD+ programme than that envisaged by the international body providing the incentive if they had worked with standard opportunity cost calculations of marginal abatement costs.

We make the following assumptions regarding the direction of the partial derivatives:

$$\frac{\partial \pi_\beta}{\partial f_\beta^*} > 0 \,, \frac{\partial \pi_\gamma}{\partial f_\beta^*} < 0 \,, \frac{\partial f_\beta^*}{\partial \varphi_\beta} < 0$$

We assume that an increase in the forest input demand, f_β^*, in the agriculture sector, *ceteris paribus*, will increase profits. The increase inf_β^* allows greater production, increasing profit levels – with the proviso that the increase inf_β^* will also drive up $\bar{z}$. We assume that the first of these effects always dominates – but at a decreasing rate thus we assume:

$$\frac{\partial^2 \pi_\beta}{\partial f_\beta^{*2}} < 0$$

We assume that an increase in f_β^*, will reduce profits in the SFM sector as it both restricts the amount of forest input available in that sector, reducing production, and also drives up the forest input price, $\bar{z}$. With the joint production technology we assume that the scale of this effect is independent of the level of f_β^* thus:

$$\frac{\partial^2 \pi_\gamma}{\partial f_\beta^{*2}} = 0$$

We assume that an increase in the level of direct payment to agriculture reduces the level of forest input demand in that sector as it both increases overall marginal costs, reducing the level of optimal output, y_β^*, and increases the relative price of forest against labour, encouraging substitution between the factors for any given level of output. We assume that this effect is constant to the level of direct payment and:

$$\frac{\partial^2 f_\beta^*}{\partial \varphi_\beta^{\,2}} = 0$$

Looking at the direct payment for the SFM sector (2) we can find the cases when there is an interior solution to the model. Given that the first term is positive and the following two terms are negative, and the fact that we assume that this payment must have a lower bound of zero[7] there is an optimum solution if:

$$\left|\frac{\partial \pi_\beta}{\partial f_\beta^*}\right| > \left|\frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right| \quad (3)$$

(3) is more likely to hold the greater the dependence of the agriculture sector on the level of forest input, as this will increase $\frac{\partial \pi_\beta}{\partial f_\beta^*}$ and will also raise the absolute level of $\frac{\partial f_\beta^*}{\partial \varphi_\beta}$ reducing the size of the right hand side. The condition will also be more likely to hold the lesser the impact of a rise on f_β^* is on the SFM sector. This depends on the scale of the impact on the forest input price, and the impact of a change in price on the SFM sector's forest level. As we have assumed in this sector that forest and labour are complimentary inputs we can assume that output in this sector is relatively inelastic to forest input price changes – making the impact of a change in price relatively small.

If we assume that condition (3) holds, direct payments to the agriculture sector, and thus incentives to reduce forest use, will be greater the smaller is the dependence of the agriculture sector on forests, the greater the responsiveness of the SFM sector to increases in forest use in agriculture through either the restriction of forest input in that sector, or through the increase in its input price), the larger the forest use in agriculture and the smaller the impact of the payment on forest levels.

Taxes

We set-up the model in a similar fashion but now assume the government faces a policy variable of an input tax, r, or an output tax, t, levied on agriculture. We assume that all revenues from these taxes are recycled to the whole population on a per-capita basis and taxes are lump sum thus:

$$z_\beta = \bar{z} + r$$
$$p_\beta = p_\beta^* + t$$

where z_β is the input price faced by agriculture. Input taxes thus drive a relative wedge between forest input prices, in the same vein as the direct payment scheme discussed above. The output tax changes the relative prices between the two production goods that producers face.

The welfare functions that the government optimises in its choice of level of each instrument become respectively:

[7] It is infeasible to believe that there could be a negative rate of payments to either sector as it would involve a transfer of income related to the baseline of forest use. It is feasible to think that a payments scheme might accompany other policies that change the relative prices – allowing income transfers – we examine the combination of a direct payment scheme with taxes in Section 5.

Input tax

$$W = 1 + \pi_\beta + \pi_\gamma + r f_\beta^* + \chi(F^* - f_\beta^*)$$

Output tax

$$W = 1 + \pi_\beta + \pi_\gamma + t y_\beta^* + \chi(F^* - f_\beta^*)$$

The results of the optimisation are summarised in Appendix 1.

Optimal input taxes are given by:

$$r = \chi - \left(\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial r}} \right) (4)$$

Optimal output taxes are:

$$t = \chi \frac{\partial f_\beta^*}{\partial y_\beta^*} - \frac{\partial \pi_\beta}{\partial y_\beta^*} - \frac{\partial \pi_\gamma}{\partial y_\beta^*} - \frac{y_\beta^*}{\frac{\partial y_\beta^*}{\partial t}} \ (5)$$

The input tax displays a direct equivalence with the direct payments results as $\frac{\partial f_\beta^*}{\partial r} = \frac{\partial f_\beta^*}{\partial \varphi_\beta}$, with the proviso that the level of the optimal input tax is not bound by condition (3) – effectively this means that the input tax could be negative unlike our assumption of non-negativity for the level of direct payments. The same general equilibrium impacts of the input tax are taken into account when determining how much of the international incentive is passed through to producers.[8] The direct payment scheme and the input tax are equivalent when there is no political influence. This is because the income transfer component of the direct payment scheme does not factor into government decision-making due to our assumptions of homogenous consumers and a government who only optimises over aggregate social welfare.

We make the following assumptions regarding direction of partial derivatives that define the output tax:

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

We assume that an increase in optimal output in agriculture will result in an increase in forest input demand in that sector. We assume that increases in optimal output in agriculture increase profits in that sector, and reduce profits in γ through driving up the forest input price, $\bar{z}$. We also assume that increases in the tax rate t reduce the level of optimal output y_β^*.

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

[8] This finding supports the discussion of the direct payments scheme as 'input tax' plus income transfers.

the determinants of each of the policy instruments in Table 1. The general equilibrium effects are given in bold.

Table 1: Determinants of optimal policy levels

Policy instrument	Determinants
Direct payment	- Level of international incentive - **Change in agricultural profits from change in forest input** - **Change in SFM profits from change in agricultural forest input** - **'Revenue effect' – level of agricultural forest input use, change in agricultural forest input from change in agricultural direct payment rate.**
Input tax	- Level of international incentive - **Change in agricultural profits from change in forest input** - **Change in SFM profits from change in agricultural forest input** - **'Revenue effect' – level of agricultural forest input use, change in agricultural forest input from change in input tax rate.**
Output tax	- Level of international incentive - **Change in agricultural forest input from change in agricultural output** - **Change in agricultural profits from change in output** - **Change in SFM profits from change in output** - **'Revenue effect' – level of output, change in agricultural output from change in output tax rate.**

4. Interest group influence

We now assume that either of the forest-using sectors, agriculture or SFM can exert some influence on government decision-making above and beyond their level of overall social welfare. We then investigate how this influence impacts upon the level of the various policy instruments. We follow the tradition of Fredriksson, (1997) which in turn builds on the characterisation of a menu auction problem by Bernhein & Whinston (1986) and the solution to the political equilibrium identified by Helpman & Grossman (1994).

As discussed above we follow and extend the literature in this area in assuming that a lobby group can offer a certain amount of influence on government decision-making. In the previous literature this is termed contributions but here we term it political influence.

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

where W is overall social welfare and C_i is the level of influence offered by sectors and μ is the relative weight put on influence and overall social welfare by the government.[9] The μ term represents the importance of lobby group influence on government decision-making – and can represent the extent to which governments make decisions for the good of their entire

[9] We assume for tractability that only one sector offers influence at any one time. If both sectors offer influence then the model again simplifies to that solved above with no political influence.

population, versus a certain subset who have political influence. If $\mu = 0$ then the model simplifies to that solved in Section 3.

C_i is assumed to be a continuous, differentiable function on the policy vector e populated by the relevant policy variables $\varphi_\beta, \varphi_\gamma, r \text{ or } t$.

Conceptually the model follows the following logic:

- One of the production good sectors has access to offer influence to the government.
- The 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 its desired realisation of *e* and receives the identified level of influence.

Following the solution to such a model identified in Fredriksson (1997) we identify $(\{C_i\}_{i\in\beta,\gamma}, [e])$ as a Subgame Perfect Nash Equilibrium if and only if,[10]

(i) $\{C_i\}_{i\in\beta,\gamma}$ is feasible

(ii) $[e]$ maximises $\mu W + C_i$ on E

(iii) There exists a $e^{-i} \in E$ that maximises $\mu W + C_i$ on E such that $C_i(e^{-i}) = 0$ for $i \in \beta, \gamma$

where E is the feasible set of *e*.

We then solve this model for the case when either agriculture or SFM is able to offer influence.[11] Following the derivation in Fredriksson (1997) and Helpman & Grossman (1994) influence is locally truthful, therefore any change in welfare is reflected in a change in influence and the condition for solving the maximisation of the government is derived as:

$$\nabla W + \mu \nabla W_i = 0$$

where W_i is the welfare of the sector which exerts influence on the government. This condition 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 sector with influence's change in welfare is zero.

Agriculture sector influence

We first assume that agriculture exerts influence upon the government implying that the government chooses a level of policy instrument that solves:

$$\nabla W + \mu \nabla W_\beta = 0$$

[10] We drop Fredriksson's third condition as we only have one lobby group offering contributions to the government at any one time.

[11] In the case where both are able to offer contributions the model simplifies to the case where only social welfare is considered as sectors are valued equally.

Agricultural (or more broadly forest-extractive industries) influence may come from economic power, organisation of industry groups, or the ability to offer payments or campaign contributions directly.

If we first examine the case where the government establishes a direct payment scheme agriculture sector welfare is:

$$W_\beta = \beta + \pi_\beta + \varphi_\beta F^*$$

Total differentiating W_β gives:

$$\frac{\partial W_\beta}{\partial \varphi_\beta} = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^*$$
$$\frac{\partial W_\beta}{\partial \varphi_\gamma} = 0$$

Thus the government solves the following first order conditions in choosing the rate of direct payments:

$$\frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* - \varphi_\gamma \frac{\partial f_\beta^*}{\partial \varphi_\beta} + \lambda + \mu\left(\frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^*\right) = 0$$

$$F^* - f_\beta^* + \lambda = 0$$

$$\varphi_\beta + \varphi_\gamma - \chi = 0$$

Solving these conditions yields the following:

$$\varphi_\beta = \chi - \left(\frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \mu \frac{\partial \beta}{\partial f_\beta^*} + \frac{\mu F^* + f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right) \quad (6)$$

$$\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \mu \frac{\partial \beta}{\partial f_\beta^*} + \frac{\mu F^* + f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \quad (7)$$

By comparing (1) and (6) and (2) and (7) we can see that the government factors in slightly amended general equilibrium effects of the direct payment scheme in determining the rate of payments. The impact on profits in agriculture is given greater weight (as we assume $\mu > 0$) – while there are two new terms: one relating to how much the size of the agriculture sector changes in relation to an increase in forest input demand; and one relating to the income component of the direct payment scheme, $\frac{\mu F^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$. We assume that the first $\frac{\partial \beta}{\partial f_\beta^*}$ is positive, as we have previously assumed that $\frac{\partial \pi_\beta}{\partial f_\beta^*} > 0$ and $\frac{\partial \pi_\gamma}{\partial f_\beta^*} < 0$ and that individuals switch between sectors related to relative profits.

The increased weight on profits will tend to reduce the rate of direct payments to agriculture, as will the inclusion of the influence on switching. In contrast the factoring in of the income component of the direct payment scheme will tend to increase direct payments to agriculture. This shows a potential dilemma; on the one hand agriculture prefers a lower direct payments rate in order to reduce the rise in the price of the forest input, with its impact on both profits and the size of the sector. On the other hand the sector would gain from a higher direct payments rate as it brings with it a higher income transfer relating to the baseline forest externality level.

Whether the rate of direct payments to agriculture (and thus incentives to reduce the externality from forest use) rises or falls depends on whether the first two effects (which we call the price effect) dominate the latter (which we shall call the income effect).

If the price effect is greater payments to agriculture fall, reducing incentives to reduce forest input in that sector, increasing the level of f_β^*. This rise inf_β^* will in turn increase the level of $\frac{\partial \pi_\beta}{\partial f_\beta^*}$. These two effects will offset part of the fall in direct payments to agriculture. If on the other hand the income effect dominates, payments to agriculture rise, increasing incentives, with the changes to $\frac{\partial \pi_\beta}{\partial f_\beta^*}$, and f_β^* offsetting some of these effects.

The direction (and scale) in which direct payments to agriculture change when there is political influence thus depends on the size of the price effect, the size of the income effect and the offsetting changes to the reactiveness of profit levels to the forest input, and the change in the tax revenue effects.

To fully see this we can take the differences between the level of direct payment to the SFM sector under no political influence and under agricultural sector influence

$$\widetilde{\varphi_\gamma} - \overline{\varphi_\gamma} = \mu\left(\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \beta}{\partial f_\beta^*} + \frac{F^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right) + \left(\widetilde{\frac{\partial \pi_\beta}{\partial f_\beta^*}} - \overline{\frac{\partial \pi_\beta}{\partial f_\beta^*}}\right) + \left(\frac{\widetilde{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\overline{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}\right) \quad (8)$$

where tildas refer to terms under agricultural sector influence and upper-bars refer to terms under no influence. The first bracketed term in (8) shows the price and income effects, while the latter terms show the changes in the reactiveness of profit levels to the forest input, and the change in the tax revenue effects.

The direction of change in the rates of direct payments to either sector – and thus the level of the international incentive passed through – depends on the balance between the price and income effects. If the price effects are greater, the impacts of reducing direct payments to agriculture on profit levels and sector size outweigh the reduced income transfer that this entails. If, on the other hand, the income effect is greater than the price effects, direct payments to agriculture and thus incentives to reduce forest input demand will rise.

Welfare will rise in the agriculture sector (by definition), while it must fall in the SFM sector as the new solution is different from the socially optimal level defined in Section 3. The scale of the welfare fall will depend on the direction and scale of the change in direct payment rates and two factors within the direct payments scheme. A higher rate in direct payments for agriculture brings positive income benefits but also brings negative price effects, and vice versa.

The same trade-off can be seen again when we look at the situation when SFM has influence. Following the same methodology as above we receive the following solution:

$$\varphi_\beta = \chi - \left(\frac{\frac{\partial \pi_\beta}{\partial f_\beta^*} + \mu \frac{\partial \gamma}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\mu\left(F^* - f_\beta\right)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right) (9)$$

$$\varphi_\gamma = \frac{\frac{\partial \pi_\beta}{\partial f_\beta^*} + \mu \frac{\partial \gamma}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\mu\left(F^* - f_\beta^*\right)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}) \ (10)$$

In a similar vein as to when agriculture has influence the government factors in amended general equilibrium effects of the direct payment scheme, compare (9) and (10) to (1) and (2). The government has a reduced influence from the impact of a change in forest input demand on profits in agriculture, it now also takes into account the impact of a change in forest input demand in agriculture on the size of SFM, and an additional term representing increased influence for the income transfer component, $\frac{\mu(F^* - f_\beta^*)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$.

To understand whether these differences mean that the direct payment rate to SFM rise or fall we calculate the differences between the rate of payment when there is SFM influence and when there is no influence. This gives the following:

$$\widehat{\varphi_\gamma} - \overline{\varphi_\gamma} = -\frac{\mu}{(1+\mu)} \left(\frac{\widehat{\partial \pi_\beta}}{\partial f_\beta^*} - \frac{\partial \gamma}{\partial f_\beta^*} + \frac{(1+\mu)\left(F^* - \widehat{f_\beta^*}\right)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right) + \left(\frac{\widehat{\partial \pi_\beta}}{\partial f_\beta^*} - \frac{\overline{\partial \pi_\beta}}{\partial f_\beta^*} \right) + \left(\frac{\widehat{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\overline{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right) (11)$$

where hats refer to terms under agricultural sector influence and over-bars again refer to terms under no influence. We assume that $\frac{\partial \gamma}{\partial f_\beta^*} < 0$, as a consequence of our earlier assumption that $\frac{\partial \beta}{\partial f_\beta^*} > 0$.

In (11) as in (7) there is both a price effect (made up of changes in the profit level of agriculture, and the level of switching between the sectors), and an income effect relating to the income transfer component of the direct payments scheme.[12] The direction of change in the rate of direct payments will again depend on which effect dominates.

The influence from SFM reduces the importance of the impact of the forest level changes on SFM sector profits – pushing up the direct payments to agriculture in order to create a greater pie from the international incentive. The inclusion of the sector switching effect works in the same direction. In contrast the extra focus on the income transfer component to the SFM sector ($\frac{(1+\mu)\left(F^{*}-\widehat{f_{\beta}^{*}}\right)}{\frac{\partial f_{\beta}^{*}}{\partial \varphi_{\beta}}}$) pushes up payments to SFM – pushing down payments to agriculture and overall incentives to reduce forest input in that sector. Which effect dominates will help to determine the direction of change in the rate of direct payments to either sector.

This result leads to the unexpected conclusion that, under certain conditions, when SFM has influence they may lobby for lower direct payment rates to themselves in order to increase the size of the overall pie – even though this will mean they obtain a smaller share of the pie. The trade-off faced by the SFM sector is whether to use their influence to increase their own rate of payments – reducing the incentive to reduce forest-use in agriculture and thus the size of the overall pie or whether to lobby for a decrease in their own payment rates – in order to strengthen the incentive in the agriculture sector to reduce forest use – increasing the size of the overall pie. The question is whether to lobby for a greater share of a smaller pie, or a smaller share of a larger pie – and the answer is indeterminate. Table 2 outlines the elements of the trade-off and highlights the indeterminacy in the direction of change in the rate of direct payments under either sectors political influence.

Table 2: Determinants of direction of change of direct payment rate to the SFM sector

Political influence	Determinants of direction of change of direct payment rate to the SFM sector	Direction
Agriculture	$Price\ effect =$ $\Delta\ agricultural\ profit\ from\ \Delta\ forest\ input\ level\ +$ $\Delta\ agriculture\ sector\ size\ from\ \Delta\ agricultural\ forest\ input\ level$	Positive
	$Income\ effect$ $=\ Baseline\ forest\ use$ $/\ \Delta\ agricultural\ forest\ level\ from\ \Delta\ direct\ payment\ rate$	Negative
SFM	$Price\ effect =$ $\Delta\ agricultural\ profit\ from\ \Delta\ forest\ input\ level\ -$ $\Delta\ SFM\ sector\ size\ from\ \Delta\ agricultural\ forest\ input\ level$	Positive
	$Income\ effect$ $=\ Difference\ baseline\ forest\ use\ and\ forest\ use\ under\ policy —$ $\Delta\ agricultural\ forest\ level\ from\ \Delta\ direct\ payment\ rate$	Negative

[12] In a similar vein as above –changes in $\frac{\partial \pi_{\beta}}{\partial f_{\beta}^{*}}$ and in the tax revenue effect are taken into account. Again they will offset some of the change in the rate of direct payments.

Input and Output taxes

We follow the same methodology to compute the levels of input and output taxes under both agriculture and SFM sector influence; full details are available in Appendix 1. We do this in order to compare the results under instruments that do not involve the unequal income transfer components that a direct payments scheme facilitates. We assume tax revenues are distributed on a per-capita basis and thus share of revenues received is separated from the incentives to reduce forest use in agriculture.

The following direction of partial derivatives result from the assumption we have made in the model set-up:

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

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

Again to understand the direction of change in these instruments – and the factors that influence this – we take the difference between the levels of the instruments when there is influence from either sector from the case when there is none. The results are summarised in Appendix 1. We use the same notation as above in describing the variables under various sector influences.

When agriculture has influence the direction of change is given by:

$$\frac{-\mu\left(\left(\widetilde{\frac{\partial \pi_\beta}{\partial r}} + \beta \overline{\frac{\partial \pi_\beta}{\partial r}}\right) - \beta \frac{\partial \pi_\gamma}{\partial r} + \left(\frac{\partial \beta}{\partial r}\right) + \frac{\partial \beta}{\partial r}\left(\widetilde{f_\beta^*}\bar{r} + \chi\left(F^* - \widetilde{f_\beta^*}\right)\right)\right) - \left(\widetilde{\frac{\partial \pi_\beta}{\partial r}} - \overline{\frac{\partial \pi_\beta}{\partial r}}\right)}{\left(\frac{\partial f_\beta^*}{\partial r}(1 + \mu\beta) + \mu \frac{\partial \beta}{\partial r} \widetilde{f_\beta^*}\right)} \quad (12)$$

The denominator of (12) is negative given the assumptions above. The numerator is positive – assuming the tax rate under no influence was greater or equal to zero – and assuming the offsetting effects of the change in differentials are small. This implies that the direction of change is negative – input taxes fall when agriculture has influence.

When SFM has influence the differences follow a similar pattern, with the difference given by:

$$\frac{\mu\left(\gamma \frac{\partial \overline{\pi_\beta}}{\partial r} - (1 + \gamma) \frac{\partial \pi_\gamma}{\partial r} - \left(\frac{\partial \gamma}{\partial r}\right) - \frac{\partial \gamma}{\partial r}\left(\widehat{f_\beta^*}\bar{r} + \left(\chi(F^* - \widehat{f_\beta^*})\right)\right)\right) - \left(\widehat{\frac{\partial \pi_\beta}{\partial r}} - \overline{\frac{\partial \pi_\beta}{\partial r}}\right)}{\left(\frac{\partial f_\beta^*}{\partial r}(1 + \mu\gamma) + \mu \frac{\partial \gamma}{\partial r} \widehat{f_\beta^*}\right)} \quad (13)$$

In (13) the denominator is negative if:

$$\left|\frac{\partial f_\beta}{\partial r}(1 + \mu\gamma)\right| > \left|\mu \frac{\partial \gamma}{\partial r} \widetilde{f_\beta}\right| \quad (14)$$

(14) holds if we assume the switching effect (i.e. the amount of operators moving between sectors in response to changing profit levels) is 'small' compared to the impact of the input tax

on the use of forest in agriculture. The numerator is positive again if we assume the offsetting effects of the changes in differentials are small. Thus when there is SFM sector influence input taxes rise – increasing the incentives to reduce forest input demand and the international externality.

With an output tax we see similar effects. Agricultural influence definitely drives down output taxes (again assuming similarly small differential changes) while SFM sector influence increases output tax levels (for full details see Appendix 1). We summarise the direction of change of each instrument under political influence in Table 3.

Table 3: Direction of change of incentives under political influence

Instrument	Political Influence	Direction of incentives to reduce agricultural forest input
Input taxes	$\boldsymbol{\beta}$	-
	$\boldsymbol{\gamma}$	+
Output taxes	$\boldsymbol{\beta}$	-
	$\boldsymbol{\gamma}$	+
Direct payments	$\boldsymbol{\beta}$	+/-
	$\boldsymbol{\gamma}$	+/-

Under policies that merely change the relative prices of outputs and inputs we see clear directional changes under political influence. When, however, instruments effect relative price changes and unequal sectoral income transfers the direction of change is ambiguous. Price effects drive incentives to reduce forest input downwards when agriculture has influence, with income effects working to drive them upwards. When SFM has influence these effects work in opposite directions. Price effects work to drive up incentives, while income effects work to drive them upwards. It is clear here that the impact of interest group influence is not necessarily clear when relative price changes and income transfers are intrinsically linked through one instrument. It is this inter-linkage that drives these ambiguous results. The trade-off faced by the γ sector, especially, between increasing incentives to reduce forest input demand in agriculture, and increasing their own share of the pie is one of these inter-linkages. We now extend the model to include multiple instruments that may allow these inter-linkages to be decoupled.

5. *Model Extensions*

Multiple instruments

We now extend the model to include multiple instruments. We assume the government can impose both a direct payments scheme and an input tax, or a direct payments scheme and an output tax. This line of research is justified from two separate directions. First taxes are already pervasive in forest sectors worldwide, often through the system of forest concessions (Gray, 2002), thus there is value from analysing the imposition of a specific REDD+ policy, such as the direct payment scheme we analyse, on existing forest taxation regimes. Secondly one of the reasons for the counter-intuitive results found in the section above were caused by the linking, through the direct payment scheme, of the size of the incentive created on the agricultural sector and the distribution of the REDD+ pie. Implementing a direct payment scheme alongside a tax allows this linkage to be separated – and allows us to examine the robustness of the counter-intuitive results.

Returning to the model overall social welfare now becomes respectively:

Direct payments and input tax:

$$W = 1 + \pi'_\beta + \pi'_\gamma + r f^*_\beta$$

Direct payments and output tax:

$$W = 1 + \pi'_\beta + \pi'_\gamma + t y^*_\beta$$

The solutions to the instruments are shown in Appendix 2 derived using the same methodology as discussed above.

No political influence

When direct payments and input taxes are imposed together we see a complete equivalence between the two instruments. In determining the rate of direct payments the level of input tax imposed is merely subtracted from the international incentive with the same suite of general equilibrium effects factored into decision making as under the case where only one of the instruments is available. Choosing between a level of direct payments and input tax does not affect the overall level of incentive created to reduce forest use in agriculture. The only impact is upon the distribution of welfare between sectors. Should the government choose a greater level of direct payments to agriculture, welfare in this sector is likely to be higher as the income transfer component of the direct payments scheme benefits individuals in the sector. If on the other hand input taxes are higher, the level of direct payments to agriculture is lower – implying a higher rate to SFM– and a higher welfare in this sector.

In the case where a direct payment scheme in introduced alongside an output tax a similar structure holds. The level of output tax is factored into the level of direct payments, scaled by $\frac{\partial y^*_\beta}{\partial f^*_\beta}$, the impact of a change in forest level on output. It is factored in alongside the identical general equilibrium effects as in the case without the tax. The level of direct payment and tax are determined by the condition:

$$\frac{f^*_\beta}{\frac{\partial f^*_\beta}{\partial \varphi_\beta}} = \frac{y^*_\beta}{\frac{\partial f^*_\beta}{\partial t_\beta}}$$

Political influence

We follow the same methodology as in earlier sections to determine the level of instruments under both agriculture and SFM sector influence. Results are in Appendix 2.

To analyse these results we again calculate the differences between the instruments under no influence and when each sector has influence. The results are shown in Appendix 2 and are discussed below.

Direct payments and input taxes

Agricultural sector influence

We find that when comparing between instruments, for any given level of input tax, the rate of payments to SFM are higher, implying that incentives to reduce forest use in agriculture are lower, if:

$$\frac{\partial \widetilde{\pi_\beta}}{\partial f_\beta^*} + \frac{\partial \beta}{\partial f_\beta^*} + \tilde{r}\left(\frac{\partial \beta}{\partial f_\beta^*}\widetilde{f_\beta^*} + \beta\right) + \ \beta \frac{\widetilde{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial r}}) > 0 \ (15)$$

assuming that the changes to differentials and forest input level that offset some of this effect are again small.[13] (15) is a similar condition to (3), discussed above in the case with just the direct payments scheme, with one addition – the third term in (15) operates in the same direction as the price effects. It effectively captures the input tax revenue (and distribution) effects. If direct payments to agriculture fall, forest input tax revenue rises. This, along with the tax revenue received by the individuals switching sectors – works in the same direction as price effects – in driving down payments to agriculture. In addition the income effect is smaller as $\beta < 1$ and $\widetilde{f_\beta^*} \leq F^*$. The inclusion of input taxes helps to reinforce the direction of change under agricultural influence, with incentives more likely to decline than when a direct payments scheme is used.

SFM sector influence

Under SFM influence we find a similar result. For a given level of input tax payments to SFM are lower, implying that incentives to reduce forest use in agriculture are higher if:

$$\frac{\overline{\partial \pi_\beta}}{\partial f_\beta^*} - \frac{\partial \gamma}{\partial f_\beta^*} - \hat{r}\left(\frac{\partial \gamma}{\partial f_\beta^*}\widehat{f_\beta^*} + (\gamma - 1)\right) + \frac{(1-\gamma)\widehat{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial r}} > 0 \ (16)$$

Again the tax income effect in (16) works in the same direction of the first two terms that make up the price effect, with the latter term representing the income effect. The upward push for incentives is strengthened by the tax income effect – although in this case the change in the income effect is ambiguous. The inclusion of the tax income effect makes it more likely that SFM influence will drive greater incentives to reduce forest input demand.

Direct payments and output tax

Agricultural sector influence

The combination of direct payments and output taxes show a similar pattern as to when direct payments and input taxes are combined.

For a set level of output tax payments to the SFM sector increase if:

$$\frac{\partial \widetilde{\pi_\beta}}{\partial f_\beta^*} + \frac{\partial \beta}{\partial f_\beta^*} + \tilde{t}\left(\beta\frac{\partial y_\beta^*}{\partial f_\beta^*} + \frac{\partial \beta}{\partial f_\beta^*}\widetilde{y_\beta}\right) + \frac{\beta \widetilde{y_\beta^*}}{\frac{\partial f_\beta^*}{\partial t}} > 0 \ (17)$$

The inclusion of the tax income effect in the third term in (17) operates in the same direction as the price effects – making declines in direct payments to agriculture, and incentives to reduce forest input use in that sector, more likely.

[13] This applies for the remaining discussion of multiple instruments and political influence in this section.

SFM sector influence

When SFM has influence we find that for a given level of output tax direct payments to the sector decrease if:

$$\overline{\frac{\partial \pi_\beta}{\partial f_\beta^*}} - \frac{\partial \gamma}{\partial f_\beta^*} - \hat{t}\left(\frac{\partial \gamma}{\partial f_\beta^*}\widehat{y_\beta^*} + (\gamma - 1)\frac{\partial y_\beta^*}{\partial f_\beta^*}\right) + \frac{\widehat{y_\beta^*}(1-\gamma)}{\frac{\partial f_\beta^*}{\partial t}} > 0 \quad (18)$$

The tax income effect in (18) makes it more likely that the overall incentives to reduce the forest externality increase.

We summarise the changes in the direction in incentives to reduce forest input use in agriculture under multiple instruments in Table 4.

Table 4: Direction of change of incentives to reduce forest input use in agriculture of multiple instruments under political influence

Instrument	Sector influence	Direction of change of incentives to reduce forest use in agriculture
Direct payments and input tax	β	-
	γ	+
Direct payments and output tax	β	-
	γ	+

Labour market constraints

We assumed earlier the presence of perfect labour markets. This is a strong assumption that is unlikely to hold in many of the jurisdictions that REDD+ is likely to function in. We discuss here the impacts of relaxing this assumption for our model.

In the base case model with REDD+ policy, but no political influence investigated in Section 3 the relaxation of assumptions regarding perfect labour markets has two main effects. If we look at the other extreme case, where labour markets are perfectly rigid, we see that in essence workers are now stuck in their individual labour sections. Any changes in demand for labour are realised here in changes in wage rates, rather than in movement of labour between sectors. We then have differentiated wages between the three sectors. Under no political influence the wage effects are factored in 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 policy levels depends on the relative balance of the change in wage rates in the two sectors. If the wage effect is stronger in the agriculture sector, than in the SFM sector tax rates 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 be amended. Forest use may be more ‘sticky’ as operators are unable to hire more labour to substitute for forest. If this is the case then the all the instruments will tend to be set at a lower level, implying less of the international incentive is passed on to the agriculture sector.

Under political influence the impact of the relaxation of perfect labour markets differs between instruments. For direct payments the sector switching effect, (e.g. $\frac{\partial \beta}{\partial \varphi_\beta}$), is merely replaced by the change in wage rates. We can safely assume that these have the same sign, but discussion over scale is more difficult.

For taxes the same sector switching effects drop out, with the wage effect included in its stead. The same changes of direction in incentives to reduce forest use in agriculture hold under agricultural and SFM sector influence.

For all instruments there is a further term added to the offsetting effects – that captures changes in wage rates. This further reinforces the offsetting elements of changes in the direction of the instruments under political influence.

When we look at the case of multiple instruments we again see the sector switching effects being replaced by the commensurate wage effects. In addition the tax revenue effect is smaller as the sector switching effect component drops out – implying that there is added ambiguity regarding the direction of change in incentives.

6. Discussion/Conclusion

We build here a model that analyse the impacts for policy choice for REDD+ of factoring in general equilibrium effects and political influence. This helps us move toward a more realistic setting in which to analyse the questions surrounding how REDD+ finance is likely to be utilised.

Our general equilibrium model allows us to highlight that the level of incentives offered internationally may not be fully passed through to the relevant sectors, if there are negative economic consequences of the policies chosen to implement them. These general equilibrium effects help to shape how the costs and benefits of REDD+ policy are distributed between an agricultural and SFM sector. The presence of general equilibrium effects are constant between different potential policies for REDD+, direct payments, input or output taxes, although for the latter the effects factored in are slightly different. Similar results are found when we look at a combination of direct payments and taxes.

The implications of these general equilibrium effects is that, if not factored into policy analysis, the incentives to reduce extractive forest use, and carbon externalities, that actually emerge on the ground, could be different from those conceived of at international level. The fact that these effects are taken into account by government in policy making starts to move us away from the marginal abatement cost methodology as the most crucial concept in understanding the potential costs of policy. If these general equilibrium effects imply that the marginal costs do not reach the ground through policy then overall costs of REDD+ policy are likely to rise.

The importance of the general equilibrium effects are further shown once we follow Helpman and Grossman in identifying the impacts of political influence from lobby groups. When we examine the impact of political influence on the rates of direct payments to the sectors involved, we find ambiguous effects. Price effects, relating to increases in the cost of using forest as an input, lead to the agricultural sector desiring lower direct payment rates, while income effects, relating to income transfers under REDD+, work in the opposite direction. The balance between these two will depend on the scale of the baseline used for REDD+, and the dependence of the sector on the forest for production – or in other words the ability to carry on production, while moving away from forest-extensive production. This leads us to the counter-intuitive conclusion that in some cases agriculture may lobby for higher rates of direct payment, if the income effect dominates the price effect.

We see similar impacts when the SFM sector has influence: whether the rate of direct payments rise or falls depends on the same price and income effects. In this case the counter-intuitive conclusion that the SFM may lobby for lower rates of direct payment, if the price effects outweigh the income effects, arises. In effect the SFM sector faces a choice between lobbying for a greater share of a smaller pie, or a smaller share of a greater pie – which one it chooses is indeterminate.

When we examine when the government implements either an input or output tax we see more determinate effects. When the agricultural sector has influence tax rates fall, when the SFM sector has influence they increase. This determinacy is a result of the separation between incentives and income distribution that results from our assumption of the per-capita distribution of revenue.

This determinacy holds when we assume the government implements a tax alongside a direct payments scheme, as again there is a separation between the scale of incentives to reduce forest input use in agriculture, from the overall income distribution.

Although for analytic simplicity we assume perfect factor markets, our results are robust to imperfections in the labour market. Our assumption of functioning forest markets is more critical to the model, helping to define the distribution of forest between sectors – and allowing instruments to shift actors between sectors.

Overall the model formulated here helps to inform the discussion of implementation of REDD+ policy, it highlights the importance of widening the scope to economy-wide effects in understanding how REDD+ may be implemented. It also highlights the importance of understanding the political economy in countries in which REDD+ may be targeted, and understanding what factors help to form policy in those countries. The model presented here is conceptual and simplistic, and extensions including a wider group of policy options, more analysis of the interaction between policy instruments, and the relaxation of assumptions such as perfect forest markets, would provide valuable additions that would move the model a step closer to reality. The extension of Helpman and Grossman's framework to an instrument that both changes relative prices and also enacts unequal income transfers, also provides a valuable extension of the methodological framework – and highlights the ambiguity of results when instruments contain these linkages. Further extensions of this framework to other realms of policy instruments relevant for REDD+ would provide both important policy and methodological extensions.

In general the model here helps to highlight the importance of taking into account wider economic and political considerations in discussing issues of policy choice for REDD+ in particular, and in environmental policy more generally.

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Appendix 1: Model results

Optimal levels of input and output tax under no influence

Input tax

$$W = 1 + \pi_\beta + \pi_\gamma + rf_\beta^* + \chi(F^* - f_\beta^*)$$

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

$$r = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial r}})$$

Output tax

$$W = 1 + \pi_\beta + \pi_\gamma + ty_\beta^* + \chi(F^* - f_\beta^*)$$

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

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

Optimal levels of input and output tax under β influence

Input tax

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

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

First order condition:

$$0 = \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} + f_\beta^* + \frac{\partial f_\beta^*}{\partial r} r - \frac{\partial f_\beta^*}{\partial r}\chi + \mu(\frac{\partial \beta}{\partial r} + \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \beta}{\partial r}\left(rf_\beta^* + \chi(F^* - f_\beta^*)\right) + \beta\left(f_\beta^* + r\frac{\partial f_\beta^*}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\chi\right))$$

$$r = \frac{\chi(\frac{\partial f_\beta^*}{\partial r}(1 + \mu\beta) - \frac{\partial \beta}{\partial r}\mu(F^* - f_\beta^*)) - \frac{\partial \pi_\beta}{\partial r}(1 + \mu) - \frac{\partial \pi_\gamma}{\partial r} - f_\beta^*(1 + \mu\beta) - \mu(\frac{\partial \beta}{\partial r})}{(\frac{\partial f_\beta^*}{\partial r}(1 + \mu\beta) + \mu\frac{\partial \beta}{\partial r} f_\beta^*)}$$

Output tax

$$W_\beta = \beta + \pi_\beta + \beta(ty_\beta^* + \chi(F^* - f_\beta^*))$$

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

First order condition:

$$0 = \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} + y_\beta^* + \frac{\partial y_\beta^*}{\partial t}t - \frac{\partial f_\beta^*}{\partial t}\chi + \mu(\frac{\partial \beta}{\partial t} + \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \beta}{\partial t}\left(ty_\beta^* + \chi(F^* - f_\beta^*)\right) + \beta\left(y_\beta^* + t\frac{\partial y_\beta^*}{\partial t} - \frac{\partial f_\beta^*}{\partial t}\chi\right))$$

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

Optimal levels of input and output tax under γ influence

Input tax

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

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

First order condition:

$$0 = \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} + f_\beta^* + \frac{\partial f_\beta^*}{\partial r}r - \frac{\partial f_\beta^*}{\partial r}\chi + \mu(\frac{\partial \gamma}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} + \frac{\partial \gamma}{\partial r}\left(rf_\beta^* + \chi(F^* - f_\beta^*)\right) + \gamma\left(f_\beta^* + r\frac{\partial f_\beta^*}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\chi\right))$$

$$r = \frac{\chi(\frac{\partial f_\beta^*}{\partial r} - \mu\frac{\partial \gamma}{\partial r}(F^* - f_\beta^*) + \mu\gamma\frac{\partial f_\beta^*}{\partial r}) - \frac{\partial \pi_\beta}{\partial r} - \frac{\partial \pi_\gamma}{\partial r}(1+\mu) - f_\beta^*(1+\mu\gamma) - \mu(\frac{\partial \gamma}{\partial r})}{\frac{\partial f_\beta^*}{\partial r}(1+\mu\gamma) + \mu\frac{\partial \gamma}{\partial r}f_\beta^*}$$

Output tax

$$W_\gamma = \gamma + \pi_\gamma + \gamma(ty_\beta^* + \chi(F^* - f_\beta^*))$$

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

$$0 = \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} + y_\beta^* + \frac{\partial y_\beta^*}{\partial t} t - \frac{\partial f_\beta^*}{\partial t}\chi + \mu(\frac{\partial \gamma}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} + \frac{\partial \gamma}{\partial t}\left(t y_\beta^* + \chi\left(F^* - f_\beta^*\right)\right)$$
$$+ \gamma\left(y_\beta^* + t\frac{\partial y_\beta^*}{\partial t} - \frac{\partial f_\beta^*}{\partial t}\chi\right))$$

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

Table 5: Optimal policy instruments with no political influence

Policy	Solution
Direct payments	$\varphi_\beta = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}})$ $\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$ $0 \leq \varphi_\beta, \varphi_\gamma \leq \chi$
Input tax	$r = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial r}})$
Output tax	$t = \chi\frac{\partial f_\beta^*}{\partial y_\beta^*} - \frac{\partial \pi_\beta}{\partial y_\beta^*} - \frac{\partial \pi_\gamma}{\partial y_\beta^*} - \frac{y_\beta^*}{\frac{\partial y_\beta^*}{\partial t}}$

Table 6: Levels of input and output tax under political influence

Instrument	Influence	
Direct payments	β	$\varphi_\beta = \chi - \left(\frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \mu \frac{\partial \beta}{\partial f_\beta^*} + \frac{\mu F^* + f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right), \qquad \varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \mu \frac{\partial \beta}{\partial f_\beta^*} + \frac{\mu F^* + f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}}$
	γ	$\varphi_\beta = \chi - \left(\frac{\frac{\partial \pi_\beta}{\partial f_\beta^*} + \mu \frac{\partial \gamma}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\mu(F^* - f_\beta)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \right), \qquad \varphi_\gamma = \frac{\frac{\partial \pi_\beta}{\partial f_\beta^*} + \mu \frac{\partial \gamma}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} - \frac{\mu(F^* - f_\beta^*)}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}})$
Input Tax	β	$r = \frac{\chi(\frac{\partial f_\beta^*}{\partial r}(1+\mu\beta) - \frac{\partial \beta}{\partial r}\mu(F^* - f_\beta^*)) - \frac{\partial \pi_\beta}{\partial r}(1+\mu) - \frac{\partial \pi_\gamma}{\partial r} - f_\beta^*(1+\mu\beta) - \mu(\frac{\partial \beta}{\partial r})}{(\frac{\partial f_\beta^*}{\partial r}(1+\mu\beta) + \mu \frac{\partial \beta}{\partial r} f_\beta^*)}$
	γ	$r = \frac{\chi(\frac{\partial f_\beta^*}{\partial r} - \mu \frac{\partial \gamma}{\partial r}(F^* - f_\beta^*) + \mu\gamma \frac{\partial f_\beta^*}{\partial r}) - \frac{\partial \pi_\beta}{\partial r} - \frac{\partial \pi_\gamma}{\partial r}(1+\mu) - f_\beta^*(1+\mu\gamma) - \mu(\frac{\partial \gamma}{\partial r})}{\frac{\partial f_\beta^*}{\partial r}(1+\mu\gamma) + \mu \frac{\partial \gamma}{\partial r} f_\beta^*}$
Output tax	β	$t = \frac{\chi\left(\frac{\partial f_\beta^*}{\partial t}(1+\mu\beta) - \frac{\partial \beta}{\partial t}\mu(F^* - f_\beta^*)\right) - \frac{\partial \pi_\beta}{\partial t}(1+\mu) - \frac{\partial \pi_\gamma}{\partial t} - y_\beta^*(1+\mu\beta) - \frac{\partial \beta}{\partial t}\mu}{\frac{\partial y_\beta^*}{\partial t}(1+\mu\beta) + \frac{\partial \beta}{\partial t}\mu y_\beta^*}$
	γ	$t = \frac{\chi\left(\frac{\partial f_\beta^*}{\partial t}(1+\mu\gamma) - \frac{\partial \gamma}{\partial t}\mu(F^* - f_\beta^*)\right) - \frac{\partial \pi_\beta}{\partial t} - \frac{\partial \pi_\gamma}{\partial t}(1+\mu) - y_\beta^*(1+\mu\gamma) - \frac{\partial \gamma}{\partial t}\mu}{\frac{\partial y_\beta^*}{\partial t}(1+\mu\gamma) + \frac{\partial \gamma}{\partial t}\mu y_\beta^*}$

Table 7: Differences between tax levels under political influence

Instrument	Differences	Solution
Input tax	Difference between β sector influence and no influence	$\tilde{r}-\bar{r}=\frac{-\mu\left(\left(\widetilde{\frac{\partial\pi_\beta}{\partial r}}+\beta\overline{\frac{\partial\pi_\beta}{\partial r}}\right)-\beta\frac{\partial\pi_\gamma}{\partial r}+\left(\frac{\partial\beta}{\partial r}\right)+\frac{\partial\beta}{\partial r}\left(\widetilde{f_\beta^*}\bar{r}+\chi\left(F^*-\widetilde{f_\beta^*}\right)\right)\right)-\left(\widetilde{\frac{\partial\pi_\beta}{\partial r}}-\overline{\frac{\partial\pi_\beta}{\partial r}}\right)}{\left(\frac{\partial f_\beta^*}{\partial r}(1+\mu\beta)+\mu\frac{\partial\beta}{\partial r}\widetilde{f_\beta^*}\right)}<0$
	Difference between γ sector influence and no influence	$\hat{r}-\bar{r}=\frac{\mu\left(\gamma\frac{\partial\overline{\pi_\beta}}{\partial r}-(1+\gamma)\frac{\partial\pi_\gamma}{\partial r}-\left(\frac{\partial\gamma}{\partial r}\right)-\frac{\partial\gamma}{\partial r}\left(\widehat{f_\beta^*}\bar{r}+\left(\chi(F^*-\widehat{f_\beta^*})\right)\right)\right)-\left(\widehat{\frac{\partial\pi_\beta}{\partial r}}-\overline{\frac{\partial\pi_\beta}{\partial r}}\right)}{\left(\frac{\partial f_\beta^*}{\partial r}(1+\mu\gamma)+\mu\frac{\partial\gamma}{\partial r}\widehat{f_\beta^*}\right)}>0$
Output tax	Difference between β sector influence and no influence	$\tilde{t}-\bar{t}=\frac{-\mu(\left(\widetilde{\frac{\partial\pi_\beta}{\partial t}}+\overline{\frac{\partial\pi_\beta}{\partial t}}\beta\right)-\beta\frac{\partial\pi_\gamma}{\partial t}+\frac{\partial\beta}{\partial t}+\frac{\partial\beta}{\partial t}(\widetilde{y_\beta^*}\bar{t}+\chi(F^*-\widetilde{f_\beta^*})))-(\widetilde{\frac{\partial\pi_\beta}{\partial t}}-\overline{\frac{\partial\pi_\beta}{\partial t}})}{\left(\frac{\partial y_\beta^*}{\partial t}(1+\mu\beta)+\frac{\partial\beta}{\partial t}\mu\widetilde{y_\beta^*}\right)}<0$
	Difference between γ sector influence and no influence	$\hat{t}-\bar{t}=\frac{\mu(\overline{\frac{\partial\pi_\beta}{\partial t}}\gamma-\frac{\partial\pi_\gamma}{\partial t}(1+\gamma)-\frac{\partial\gamma}{\partial t}-\frac{\partial\gamma}{\partial t}(\widehat{y_\beta^*}\bar{t}+\chi(F^*-\widehat{f_\beta^*})))-(\widetilde{\frac{\partial\pi_\beta}{\partial t}}-\overline{\frac{\partial\pi_\beta}{\partial t}})}{\left(\frac{\partial y_\beta^*}{\partial t}(1+\mu\gamma)+\frac{\partial\gamma}{\partial t}\mu y_\beta^*\right)}>0$

Appendix 2: Multiple instruments

Optimal levels of direct payments with input taxes under no influence

$$W = 1 + \pi'_\beta + \pi'_\gamma + r f^*_\beta$$

First order conditions:

$$\frac{\partial W}{\partial \varphi_\beta} = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial \varphi_\beta} + \lambda + r\frac{\partial f^*_\beta}{\partial \varphi_\beta}$$

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

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

$$\frac{\partial W}{\partial r} = \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} - \frac{\partial f^*_\beta}{\partial r}\varphi_\gamma + f^*_\beta + \frac{\partial f^*_\beta}{\partial r} r$$

Solving gives:

$$\varphi_\beta = \chi - \left(\frac{\partial \pi_\beta}{\partial f^*_\beta} + \frac{\partial \pi_\gamma}{\partial f^*_\beta} + \frac{f^*_\beta}{\frac{\partial f^*_\beta}{\partial r}} + r\right)$$

$$\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f^*_\beta} + \frac{\partial \pi_\gamma}{\partial f^*_\beta} + \frac{f^*_\beta}{\frac{\partial f^*_\beta}{\partial \varphi_\beta}} + r$$

Optimal levels of direct payments with input taxes under β influence

$$W_\beta = \beta + \pi_\beta + \varphi_\beta F^* + \beta r f^*_\beta$$

$$\frac{\partial W_\beta}{\partial \varphi_\beta} = \frac{\partial \beta}{\partial \varphi_\beta} + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \beta}{\partial \varphi_\beta} r f^*_\beta + \frac{\partial f^*_\beta}{\partial \varphi_\beta}\beta r$$

$$\frac{\partial W_\beta}{\partial \varphi_\gamma} = 0$$

$$\frac{\partial W_\beta}{\partial r} = \frac{\partial \beta}{\partial r} + \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \beta}{\partial r} r f^*_\beta + \beta f^*_\beta + \beta r \frac{\partial f^*_\beta}{\partial r}$$

First order conditions:

$$0 = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial \varphi_\beta} + \lambda + r\frac{\partial f^*_\beta}{\partial \varphi_\beta} + \mu\left(\frac{\partial \beta}{\partial \varphi_\beta} + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \beta}{\partial \varphi_\beta} r f^*_\beta + \frac{\partial f^*_\beta}{\partial \varphi_\beta}\beta r\right)$$

$$0 = \left(F^* - f_\beta^*\right) + \lambda$$

$$0 = \varphi_\beta + \varphi_\gamma - \chi$$

$$0 = \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\varphi_\gamma + f_\beta^* + \frac{\partial f_\beta^*}{\partial r}r + \mu(\frac{\partial \beta}{\partial r} + \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \beta}{\partial r}rf_\beta^* + \beta f_\beta^* + \beta r\frac{\partial f_\beta^*}{\partial r})$$

Solving gives:

$$\varphi_\beta = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{f_\beta^*(1+\mu\beta)}{\frac{\partial f_\beta^*}{\partial r}} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + r\left((1+\mu\beta) + \mu\frac{\partial \beta}{\partial f_\beta^*}f_\beta^*\right) + \mu\frac{\partial \beta}{\partial f_\beta^*})$$

$$\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{f_\beta^*(1+\mu\beta)}{\frac{\partial f_\beta^*}{\partial r}} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + r\left((1+\mu\beta) + \mu\frac{\partial \beta}{\partial f_\beta^*}f_\beta^*\right) + \mu\frac{\partial \beta}{\partial f_\beta^*}$$

$$\lambda \le -\left(F^* - f_\beta^*\right)(1+\mu) - \mu f_\beta^*(1-\beta)$$

Optimal levels of direct payments with input taxes under γ influence

$$W_\gamma = \gamma + \pi_\gamma + \varphi_\gamma(F^* - f_\beta^*) + \gamma r f_\beta^*$$

$$\frac{\partial W_\gamma}{\partial \varphi_\beta} = \frac{\partial \gamma}{\partial \varphi_\beta} + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma\frac{\partial f_\beta^*}{\partial \varphi_\beta} + \frac{\partial \gamma}{\partial \varphi_\beta}rf_\beta^* + \frac{\partial f_\beta^*}{\partial \varphi_\beta}\gamma r$$

$$\frac{\partial W_\gamma}{\partial \varphi_\gamma} = (F^* - f_\beta^*)$$

$$\frac{\partial W_\gamma}{\partial r} = \frac{\partial \gamma}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} - \varphi_\gamma\frac{\partial f_\beta^*}{\partial r} + \gamma f_\beta^* + \frac{\partial \gamma}{\partial r}rf_\beta^* + \frac{\partial f_\beta^*}{\partial r}\gamma r$$

First order conditions:

$$0 = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma\frac{\partial f_\beta^*}{\partial \varphi_\beta} + \lambda + r\frac{\partial f_\beta^*}{\partial \varphi_\beta} + \mu(\frac{\partial \gamma}{\partial \varphi_\beta} + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma\frac{\partial f_\beta^*}{\partial \varphi_\beta} + \frac{\partial \gamma}{\partial \varphi_\beta}rf_\beta^* + \frac{\partial f_\beta^*}{\partial \varphi_\beta}\gamma r)$$

$$0 = \left(F^* - f_\beta^*\right) + \lambda + \mu(F^* - f_\beta^*)$$

$$0 = \varphi_\beta + \varphi_\gamma - \chi$$

$$0 = \frac{\partial \pi_\beta}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} - \frac{\partial f_\beta^*}{\partial r}\varphi_\gamma + f_\beta^* + \frac{\partial f_\beta^*}{\partial r} r + \mu(\frac{\partial \gamma}{\partial r} + \frac{\partial \pi_\gamma}{\partial r} - \varphi_\gamma \frac{\partial f_\beta^*}{\partial r} + \gamma f_\beta^* + \frac{\partial \gamma}{\partial r} r f_\beta^* + \frac{\partial f_\beta^*}{\partial r}\gamma r)$$

Solving gives:

$$\varphi_\beta = \chi - (\frac{\frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*(1+\mu\gamma)}{\frac{\partial f_\beta^*}{\partial r}(1+\mu)} + r\left(\frac{(1+\mu\gamma)}{(1+\mu)} + \frac{\mu \frac{\partial \gamma}{\partial f_\beta^*} f_\beta^*}{(1+\mu)}\right) + \frac{\mu}{(1+\mu)}\left(\frac{\partial \gamma}{\partial f_\beta^*}\right))$$

$$\varphi_\gamma = \frac{\frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*(1+\mu\gamma)}{\frac{\partial f_\beta^*}{\partial r}(1+\mu)} + r\left(\frac{(1+\mu\gamma)}{(1+\mu)} + \frac{\mu \frac{\partial \gamma}{\partial f_\beta^*} f_\beta^*}{(1+\mu)}\right) + \frac{\mu}{(1+\mu)}\left(\frac{\partial \gamma}{\partial f_\beta^*}\right)$$

$$\lambda \leq -\left(F^* - f_\beta^*\right) + \mu f_\beta^*$$

Optimal levels of direct payments with output taxes under no influence

$$W = 1 + \pi'_\beta + \pi'_\gamma + t y_\beta^*$$

$$\frac{\partial W}{\partial \varphi_\beta} = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f_\beta^*}{\partial \varphi_\beta} + \lambda + t\frac{\partial y_\beta^*}{\partial \varphi_\beta}$$

$$\frac{\partial W}{\partial \varphi_\gamma} = \left(F^* - f_\beta^*\right) + \lambda$$

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

$$\frac{\partial W}{\partial t} = \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} - \frac{\partial f_\beta^*}{\partial t}\varphi_\gamma + y_\beta^* + \frac{\partial y_\beta^*}{\partial t} t$$

Solving gives:

$$\varphi_\beta = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{y_\beta^*}{\frac{\partial f_\beta^*}{\partial t}} + t\frac{\partial y_\beta^*}{\partial f_\beta^*})$$

$$\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{y_\beta^*}{\frac{\partial f_\beta^*}{\partial t}} + t\frac{\partial y_\beta^*}{\partial f_\beta^*}$$

subject to:

$$\frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} = \frac{y_\beta^*}{\frac{\partial f_\beta^*}{\partial t}}$$

Optimal levels of direct payments with output taxes under $\boldsymbol{\beta}$ influence

$$W_\beta = \beta + \pi_\beta + \varphi_\beta F^* + \beta t y_\beta^*$$

$$\frac{\partial W_\beta}{\partial \varphi_\beta} = \frac{\partial \beta}{\partial \varphi_\beta} + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \beta}{\partial \varphi_\beta} t y_\beta^* + \frac{\partial y_\beta^*}{\partial \varphi_\beta} \beta t$$

$$\frac{\partial W_\beta}{\partial \varphi_\gamma} = 0$$

$$\frac{\partial W_\beta}{\partial t} = \frac{\partial \beta}{\partial t} + \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \beta}{\partial t} t y_\beta^* + \beta y_\beta^* + \frac{\partial y_\beta^*}{\partial t} \beta t$$

First order conditions:

$$0 = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f_\beta^*}{\partial \varphi_\beta} + \lambda + t \frac{\partial y_\beta^*}{\partial \varphi_\beta} + \mu\left(\frac{\partial \beta}{\partial \varphi_\beta} + \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \beta}{\partial \varphi_\beta} t y_\beta^* + \frac{\partial y_\beta^*}{\partial \varphi_\beta} \beta t\right)$$

$$0 = \left(F^* - f_\beta^*\right) + \lambda$$

$$0 = \varphi_\beta + \varphi_\gamma - \chi$$

$$0 = \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} - \frac{\partial f_\beta^*}{\partial t} \varphi_\gamma + y_\beta^* + \frac{\partial y_\beta^*}{\partial t} t + \mu\left(\frac{\partial \beta}{\partial t} + \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \beta}{\partial t} t y_\beta^* + \beta y_\beta^* + \frac{\partial y_\beta^*}{\partial t} \beta t\right)$$

Solving and using the constraints that $\varphi_\beta, \varphi_\gamma \geq 0$ gives:

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

$$\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + y_\beta^*(1+\mu\beta) + t \frac{\partial y_\beta^*}{\partial f_\beta^*}(1+\mu\beta) + \mu \frac{\partial \beta}{\partial f_\beta^*}\left(1 + t y_\beta^*\right)$$

$$\lambda \leq f_\beta^* - F^*$$

Subject to:

$$\frac{F^*(1+\mu) + \lambda}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} \geq \frac{y_\beta^*(1+\mu\beta)}{\frac{\partial f_\beta^*}{\partial t}}$$

Optimal levels of direct payments with output taxes under $\boldsymbol{\gamma}$ influence

$$W_\gamma = \gamma + \pi_\gamma + \varphi_\gamma(F^* - f^*_\beta) + \gamma t y^*_\beta$$

$$\frac{\partial W_\gamma}{\partial \varphi_\beta} = \frac{\partial \gamma}{\partial \varphi_\beta} + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial \varphi_\beta} + \frac{\partial \gamma}{\partial \varphi_\beta} t y^*_\beta + \frac{\partial y^*_\beta}{\partial \varphi_\beta}\gamma t$$

$$\frac{\partial W_\gamma}{\partial \varphi_\gamma} = (F^* - f^*_\beta)$$

$$\frac{\partial W_\gamma}{\partial t} = \frac{\partial \gamma}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial t} + \frac{\partial \gamma}{\partial t} t y^*_\beta + \gamma y^*_\beta + \frac{\partial y^*_\beta}{\partial t}\gamma t$$

First order conditions:

$$0 = \frac{\partial \pi_\beta}{\partial \varphi_\beta} + F^* + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial \varphi_\beta} + \lambda + t\frac{\partial y^*_\beta}{\partial \varphi_\beta} + \mu(\frac{\partial \gamma}{\partial \varphi_\beta} + \frac{\partial \pi_\gamma}{\partial \varphi_\beta} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial \varphi_\beta} + \frac{\partial \gamma}{\partial \varphi_\beta} t y^*_\beta + \frac{\partial y^*_\beta}{\partial \varphi_\beta}\gamma t)$$

$$0 = \left(F^* - f^*_\beta\right) + \lambda + \mu\left(F^* - f^*_\beta\right)$$

$$0 = \varphi_\beta + \varphi_\gamma - \chi$$

$$0 = \frac{\partial \pi_\beta}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} - \frac{\partial f^*_\beta}{\partial t}\varphi_\gamma + y^*_\beta + \frac{\partial y^*_\beta}{\partial t} t + \mu(\frac{\partial \gamma}{\partial t} + \frac{\partial \pi_\gamma}{\partial t} - \varphi_\gamma \frac{\partial f^*_\beta}{\partial t} + \frac{\partial \gamma}{\partial t} t y^*_\beta + \gamma y^*_\beta + \frac{\partial y^*_\beta}{\partial t}\gamma t)$$

Solving and using the constraints that $\varphi_\beta, \varphi_\gamma \geq 0$ gives:

$$\varphi_\beta = \chi - (\frac{\frac{\partial \pi_\beta}{\partial f^*_\beta}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f^*_\beta} + \frac{(1+\mu\gamma)}{(1+\mu)}(\frac{y^*_\beta}{\frac{\partial f^*_\beta}{\partial t}} + \left(t\frac{\partial y^*_\beta}{\partial f^*_\beta}\right)) + \frac{\mu}{(1+\mu)}(\frac{\partial \gamma}{\partial f^*_\beta}\left(1 + t y^*_\beta\right)))$$

$$\varphi_\gamma = \frac{\frac{\partial \pi_\beta}{\partial f^*_\beta}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f^*_\beta} + \frac{(1+\mu\gamma)}{(1+\mu)}(\frac{y^*_\beta}{\frac{\partial f^*_\beta}{\partial t}} + \left(t\frac{\partial y^*_\beta}{\partial f^*_\beta}\right)) + \frac{\mu}{(1+\mu)}(\frac{\partial \gamma}{\partial f^*_\beta}(1 + t y^*_\beta))$$

$$\lambda \leq \left(f^*_\beta - F^*\right)(1+\mu)$$

Subject to:

$$\frac{F^* + \lambda}{\frac{\partial f^*_\beta}{\partial \varphi_\beta}(1+\mu)} \geq \frac{y^*_\beta(1+\mu\gamma)}{\frac{\partial f^*_\beta}{\partial t}(1+\mu)}$$

Table 8: Instrument levels with multiple policies

Instrument	Influence	Solution
Direct payments and input tax	None	$\varphi_\beta = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} + r)$ $\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*}{\frac{\partial f_\beta^*}{\partial \varphi_\beta}} + r$
	β	$\varphi_\beta = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{f_\beta^*(1+\mu\beta)}{\frac{\partial f_\beta^*}{\partial r}} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + r\left((1+\mu\beta) + \mu\frac{\partial \beta}{\partial f_\beta^*}f_\beta^*\right) + \mu\frac{\partial \beta}{\partial f_\beta^*})$ $\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{f_\beta^*(1+\mu\beta)}{\frac{\partial f_\beta^*}{\partial r}} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + r\left((1+\mu\beta) + \mu\frac{\partial \beta}{\partial f_\beta^*}f_\beta^*\right) + \mu\frac{\partial \beta}{\partial f_\beta^*}$
	γ	$\varphi_\beta = \chi - (\frac{\frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*(1+\mu\gamma)}{\frac{\partial f_\beta^*}{\partial r}(1+\mu)} + r\left(\frac{(1+\mu\gamma)}{(1+\mu)} + \frac{\mu\frac{\partial \gamma}{\partial f_\beta^*}f_\beta^*}{(1+\mu)}\right) + \frac{\mu}{(1+\mu)}\left(\frac{\partial \gamma}{\partial f_\beta^*}\right))$ $\varphi_\gamma = \frac{\frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{f_\beta^*(1+\mu\gamma)}{\frac{\partial f_\beta^*}{\partial r}(1+\mu)} + r\left(\frac{(1+\mu\gamma)}{(1+\mu)} + \frac{\mu\frac{\partial \gamma}{\partial f_\beta^*}f_\beta^*}{(1+\mu)}\right) + \frac{\mu}{(1+\mu)}\left(\frac{\partial \gamma}{\partial f_\beta^*}\right)$
Direct payments and output tax	None	$\varphi_\beta = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{y_\beta^*}{\frac{\partial f_\beta^*}{\partial t}} + t\frac{\partial y_\beta^*}{\partial f_\beta^*})$ $\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{y_\beta^*}{\frac{\partial f_\beta^*}{\partial t}} + t\frac{\partial y_\beta^*}{\partial f_\beta^*}$

	β	$\varphi_\beta = \chi - (\frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + y_\beta^*(1+\mu\beta) + t\frac{\partial y_\beta^*}{\partial f_\beta^*}(1+\mu\beta) + \mu\frac{\partial \beta}{\partial f_\beta^*}\left(1+ty_\beta^*\right))$ $\varphi_\gamma = \frac{\partial \pi_\beta}{\partial f_\beta^*}(1+\mu) + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + y_\beta^*(1+\mu\beta) + t\frac{\partial y_\beta^*}{\partial f_\beta^*}(1+\mu\beta) + \mu\frac{\partial \beta}{\partial f_\beta^*}\left(1+ty_\beta^*\right)$
	γ	$\varphi_\beta = \chi - (\frac{\frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{(1+\mu\gamma)}{(1+\mu)}(\frac{y_\beta^*}{\frac{\partial f_\beta^*}{\partial t}} + \left(t\frac{\partial y_\beta^*}{\partial f_\beta^*}\right)) + \frac{\mu}{(1+\mu)}(\frac{\partial \gamma}{\partial f_\beta^*}\left(1+ty_\beta^*\right)))$ $\varphi_\gamma = \frac{\frac{\partial \pi_\beta}{\partial f_\beta^*}}{(1+\mu)} + \frac{\partial \pi_\gamma}{\partial f_\beta^*} + \frac{(1+\mu\gamma)}{(1+\mu)}(\frac{y_\beta^*}{\frac{\partial f_\beta^*}{\partial t}} + \left(t\frac{\partial y_\beta^*}{\partial f_\beta^*}\right)) + \frac{\mu}{(1+\mu)}(\frac{\partial \gamma}{\partial f_\beta^*}(1+ty_\beta^*))$

Table 9: Changes in instrument under political influence with multiple policies

Instrument	Difference	Result
Direct payments and input taxes	Difference β and no influence	$\widetilde{\varphi_\gamma} - \overline{\varphi_\gamma} = \mu\left(\frac{\partial\widetilde{\pi_\beta}}{\partial f_\beta^*} + \frac{\partial\beta}{\partial f_\beta^*} + \tilde{r}\left(\frac{\partial\beta}{\partial f_\beta^*}\widetilde{f_\beta^*} + \beta\right) + \beta\frac{\widetilde{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial r}}\right) + \left(\frac{\partial\widetilde{\pi_\beta}}{\partial f_\beta^*} - \frac{\overline{\partial\pi_\beta}}{\partial f_\beta^*}\right) + + \left(\frac{\widetilde{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial\varphi_\beta}} - \frac{\overline{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial\varphi_\beta}}\right) + (\tilde{r} - \bar{r})$
	Difference γ and no influence	$\widehat{\varphi_\gamma} - \overline{\varphi_\gamma} = \frac{-\mu}{(1+\mu)}\left(\frac{\overline{\partial\pi_\beta}}{\partial f_\beta^*} - \frac{\partial\gamma}{\partial f_\beta^*} - \hat{r}(\frac{\partial\gamma}{\partial f_\beta^*}\widehat{f_\beta^*} + (\gamma - 1)) + \frac{(1-\gamma)\widehat{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial r}}\right) + \left(\frac{\partial\widehat{\pi_\beta}}{\partial f_\beta^*} - \frac{\overline{\partial\pi_\beta}}{\partial f_\beta^*}\right) + + \left(\frac{\widehat{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial\varphi_\beta}} - \frac{\overline{f_\beta^*}}{\frac{\partial f_\beta^*}{\partial\varphi_\beta}}\right) + (\hat{r} - \bar{r})$
Direct payments and output taxes	Difference β and no influence	$\widetilde{\varphi_\gamma} - \overline{\varphi_\gamma} = \mu\left(\frac{\partial\widetilde{\pi_\beta}}{\partial f_\beta^*} + \frac{\partial\beta}{\partial f_\beta^*} + \tilde{t}\left(\beta\frac{\partial y_\beta^*}{\partial f_\beta^*} + \frac{\partial\beta}{\partial f_\beta^*}\widetilde{y_\beta}\right) + \frac{\beta\widetilde{y_\beta^*}}{\frac{\partial f_\beta^*}{\partial t}}\right) + \left(\frac{\partial\widetilde{\pi_\beta}}{\partial f_\beta^*} - \frac{\overline{\partial\pi_\beta}}{\partial f_\beta^*}\right) + \frac{(\widetilde{y_\beta^*} - \overline{y_\beta^*}) + (\tilde{t} - \bar{t})\frac{\partial y_\beta^*}{\partial t}}{\frac{\partial f_\beta^*}{\partial t}}$
	Difference γ and no influence	$\widehat{\varphi_\gamma} - \overline{\varphi_\gamma} = -\frac{\mu}{(1+\mu)}\left(\frac{\overline{\partial\pi_\beta}}{\partial f_\beta^*} - \frac{\partial\gamma}{\partial f_\beta^*} - \hat{t}\left(\frac{\partial\gamma}{\partial f_\beta^*}\widehat{y_\beta^*} + (\gamma - 1)\frac{\partial y_\beta^*}{\partial f_\beta^*}\right) + \frac{\widehat{y_\beta^*}(1-\gamma)}{\frac{\partial f_\beta^*}{\partial t}}\right) + \frac{(\frac{\partial\widehat{\pi_\beta}}{\partial f_\beta^*} - \frac{\overline{\partial\pi_\beta}}{\partial f_\beta^*})}{(1+\mu)} + \frac{\widehat{y_\beta^*} - \overline{y_\beta^*} + (\hat{t} - \bar{t})\frac{\partial y_\beta^*}{\partial t}}{\frac{\partial f_\beta^*}{\partial t}}$