School of Economic Sciences

Working Paper Series
WP 2013-14

The Role of Government Spending on Deforestation and Carbon Dioxide Emissions from Land Use Change

By

Gregmar Galinato and Suzette Galinato

October 2013

The Role of Government Spending on Deforestation and Carbon Dioxide Emissions from Land Use Change

Gregmar I. Galinato[a,*]

[a]School of Economic Sciences, PO Box 646210, Washington State University, Pullman, Washington 99164 USA. Tel: 1-509-335-6382. Fax: 1-509-335-1173. Email: ggalinato@wsu.edu. *Corresponding author.

Suzette P. Galinato[b]

[b]IMPACT Center, School of Economic Sciences, PO Box 646210, Washington State University, Pullman, Washington 99164 USA. Email: sgalinato@wsu.edu.

The Role of Government Spending on Deforestation and Carbon Dioxide Emissions from Land Use Change

ABSTRACT. There has been a shift in fiscal policies in developing countries with good quality institutions. Government spending is less likely to be procyclical and instead countercyclical where spending rises during times of recession and falls during times of expansion to reduce the effects of the business cycle. We show using a theoretical model that moving towards a countercyclical spending pattern yields an unintended consequence: during times of recession there is an increase in deforestation and carbon dioxide emissions from land use change. We empirically test the results from our theoretical model and find that an increase in total government spending significantly increases forest land clearing for agricultural production in the short run leading to more carbon dioxide emissions. In the long run, there is a lower steady-state forest biomass and carbon dioxide emissions are significantly higher than in the short run.

Keywords: Carbon dioxide emission, deforestation, government spending, public goods expenditure

JEL classification: H11, H20, O13, Q23

I. Introduction

The recent global recession has affected the level and composition of public expenditures in developing countries. Historically, developing countries tended towards procyclical spending where spending is cut during recessions but increased during expansions. However, over the past decade, there has been a shift in fiscal policies in emerging markets with good quality institutions towards countercyclical spending where spending rises during recessions to counter the effects of the business cycle (Frankel et al., 2011). Aside from the change in the level of spending, the composition of fiscal spending also changes during recessions as more social safety nets are put in place (Williams et al., 2012).

Recent empirical work showed that changes in the level and composition of fiscal spending significantly affect pollution levels (Bernauer and Koubi, 2006; Halkos and Paizanos, 2013; Lopez et al., 2011; López and Palacios, forthcoming). Most of the pollution analyzed deals with pollution as a by-product during the production process such as sulfur dioxide, lead and biological oxygen demand. We are only aware of one study that linked the effect of fiscal spending on carbon dioxide (Halkos and Paizanos, 2013), a leading contributor to greenhouse gas emissions, but this study also focuses on carbon dioxide through the production process. Given that the main contributors of greenhouse gas emissions in the developing world is through land use change (Crutzen and Andreae, 1990; Naughton-Treves, 2004), it is surprising that the connection between fiscal policy spending on greenhouse gas emissions through deforestation has not yet been systematically analyzed especially when fiscal policies shift toward countercyclical spending.

This article fills this gap in the literature by determining the long-run and short-run effects of fiscal policies on forest cover and deforestation-induced carbon dioxide emissions. We develop a theoretical model that links the effect of the level and composition of public expenditure on carbon dioxide emissions via changes in forest cover. This allows us to understand the mechanism relating fiscal policies and carbon dioxide emissions due to deforestation in developing countries. Using the theoretical model, we empirically measure the effect of changes in public expenditure size and composition on carbon dioxide emissions in the short run and long run. Our results have significant policy implications because we are able to predict the potential effects of fiscal policies during economic downturns on the environment which may lead to policy recommendations that ameliorate such effects.

The factors affecting deforestation are classified as direct or underlying factors where the former refer to factors that immediately cause deforestation while underlying factors are those that influence the severity of direct factors. In developing countries, one of the most common direct factors is the clearing of forest land for agricultural production (López 1997).[1] Public expenditures are an example of underlying factors that affect the conversion of forest land to agricultural land.

In order to understand how government spending affects the underlying mechanisms influencing deforestation, we focus on how distinct types of government spending influence these underlying factors. The composition of public expenditure can be delineated based on a taxonomy proposed by Lopez and Galinato (2007) that classifies two types of spending based on their effect on market efficiency. The first type is called "expenditures on public goods" which are government expenditures that alleviate market failure; for example, spending on health and

[1] Road building and logging are two other important direct factors of deforestation. Recent estimates by Galinato and Galinato (2012, 2013) show that the effect of underlying factors through roads are significantly smaller in magnitude than through forest land clearing for agricultural production. Also, since initial logging is often followed by agricultural production in developing countries (Lopez and Galinato, 2005), it is difficult to empirically separate the two direct factors on deforestation. Thus, we opt to focus our analysis on only one direct factor: agricultural production. Note that we only focus on crop production and not livestock production because the mechanisms by which public spending affects deforestation may differ between the two production technologies.

education to alleviate credit market constraints, spending on the environment to reduce pollution, spending on natural resources to establish property rights, spending on research and development to internalize positive spillover effects and spending on the optimal provision of public goods. On the other hand, "expenditures on private goods" refer to government expenditures that do not alleviate market failure and may even exacerbate market efficiency. Agricultural subsidies, subsidies to fossil fuel production and credit tax breaks to specific firms are examples of such expenditures.

Expenditures on public goods can affect the choice to clear forest land through the cost of land clearing and agricultural productivity. Expenditures on public goods allow for the creation of institutions that enforce laws that protect property rights (Polinsky and Shavell, 2000; Williamson 2000) and are essential to sustainable use of natural resource stocks. Furthermore, the provision of public goods complements other inputs in different sectors thereby augmenting agricultural productivity (Lopez et al., 2011). Expenditures on private goods are usually targeted towards specific sectors. Agricultural subsidies such as irrigation subsidies and input subsidies in South America (Bulte et al., 2007) are classic examples of such types of spending and also tend to increase agricultural productivity.

Early empirical work relied on reduced form estimation using cross-country forest cover data (Cropper and Griffiths, 1994; Shafik ,1994; Southgate, 1994; Antle and Heidebrink, 1995) to allow for a broad measure of the effect of underlying factors on deforestation. However, the mechanisms by which those factors affect forest cover are not elucidated which can hinder accurate policy prescriptions to reduce deforestation.

More recent empirical estimates from micro studies rely on data from local surveys, remote sensing and satellite images (Cropper et al., 2001; Chomitz and Thomas, 2003; López, 1997, 2000). Using detailed forest data has the advantage of obtaining accurate measures of the direct factors affecting deforestation but given the local nature of the forest cover data and limited observations over time, it is difficult to measure the effect of the underlying factors.

López and Galinato (2005) developed a methodology to bridge the link between underlying factors with estimates from micro studies by formulating a structural framework that combines elasticities from microstudies with elasticities from regressions explaining the determinants of direct factors of deforestation. Galinato and Galinato (2013) extended the analysis by including more countries and focusing on the short-run and long-run effects of political stability and corruption control on deforestation. Galinato and Galinato (2012) simulated the effects of the two governance variables on deforestation-induced carbon emissions.

We add to the literature by focusing on the effect of the level and composition of public spending as our main underlying factors affecting the direct factor of deforestation, which is forest land clearing for production of agricultural crops. Using these estimates we are able to simulate the potential effect of changes in fiscal policy on carbon release from deforestation. This is the first study we are aware of that distinguishes the long-run and short-run effects of government spending on forest cover and deforestation-induced carbon emissions.

Our theoretical model shows that when the marginal cost of land clearing brought about by an increase in expenditures on public goods is lower than the value of marginal product from such expenditure, there is more forest land cleared in the short run leading to a lower steady-state forest biomass and more carbon dioxide emitted. The effects are more pronounced when total government spending is considered since the value of marginal product of agriculture is higher with the contribution of expenditures on private goods. Our empirical model finds support for our theoretical results. We show that expenditures on public goods alone have a positive but insignificant effect on forest land clearing for agricultural production due to the countervailing effects of higher marginal cost of land clearing and higher value of marginal product of agriculture. However, total government spending significantly increases forest land clearing in the short run leading to a lower steady-state forest biomass in the long run. The impact of government spending on deforestation-induced carbon dioxide is significantly larger in the long run than the short run.

Our results highlight two important contributions. First, we show the difference in the mechanisms by which government spending affects production-based pollution versus pollution from land use change. Lopez et al. (2011) showed in their model that a change in the composition of government spending towards expenditures on public goods significantly reduces pollution but simply increasing total spending has no significant effect. In contrast, we find the opposite when a change in government spending composition has no effect on deforestation-induced carbon dioxide emissions because of a simultaneous increase in the marginal cost and marginal benefits of land clearing. However, we also show that the level of government spending significantly increases pollution from forest land clearing. Second, we find an unintended consequence when developing countries adopt countercyclical spending policies: during times of recession, more pressure may be placed on clearing forest land to produce agricultural crops leading to more carbon dioxide emissions in the short run and the long run.

In the next section we present the theoretical framework which serves as the foundation for the empirical model in Section 3. Section 4 describes the data. Section 5 presents the empirical estimates and simulations. We conclude the study in the final section.

II. Theoretical Model

We consider a two-sector economy with a dynamic natural resource stock. A manufacturing sector exists that mainly uses labor while the primary sector is agriculture and uses labor, capital and natural resources as factors of production. We focus on agricultural production in developing economies with tropical areas such as Brazil. Here, farmers clear forest land in order to cultivate cash crops that may be exported to other countries and may establish ownership through use of the land. Given the open access nature of the forest stock, we assume that farmers do not internalize their effect on the forest biomass and carbon release. Thus, they do *not* maximize discounted profits over time but instead maximize their own profit during each time period and consider the stock as exogenous.

2.1 Assumptions

The government affects both sectors of the economy based on their allocation of total public expenditure, G. They may allocate government spending to expenditures on public goods that alleviates market failure, g. In this case we focus on spending to alleviate the negative externalities under open access property rights regimes and the provision of public goods such as road systems and new agricultural technology from research and development. On the other hand, the government may also decide to focus on expenditures on private goods that subsidize firm production without alleviating market failure, x. Expenditures on public goods benefit both sectors in the economy while expenditures on private goods only affect farmers. Here, we assume that the government's budget constraint holds where $G=g+x$.

We assume that labor is mobile between the two sectors and wage is endogenously determined. Aggregate labor is fixed and is fully employed. Furthermore, capital may be purchased outside of the economy at a given world price. Finally, output prices are taken as given because markets are competitive.

Agricultural output depends not only on the amount of forest land cleared but also the forest stock because soil quality is dependent on forest biomass. Aggregate production in the agricultural sector can be written as,

(1) $Y^A = Y^A(K, L^A, F, A; g, x)$

where Y^A is output in agriculture, L^A is labor in agriculture, K is capital purchased in the world market, A is amount of land cleared and F is forest biomass.[2] We assume that the production function is constant returns to scale, increasing and concave in the four inputs of production. Furthermore, we assume that g complements K and L^A such that $Y^A_{Kg} > 0$ and $Y^A_{L^A g} > 0$, but x complements L^A and substitutes for K (Lopez et al., 2011) such that $Y^A_{Kx} < 0$ and $Y^A_{L^A x} > 0$.[3]

For a given level of forest land cleared for agricultural production, the stock of forest biomass declines by a proportion β. We assume that the natural growth rate of the forest equals α leading to a stock of forest biomass of the form,

(2) $\dot{F} = \alpha F - \beta A,$

where $\dot{F}$ is the change in forest biomass over time.

Due to the change in forest biomass, there is also a corresponding change in the amount of carbon released into the atmosphere. There is a constant rate of carbon emitted from other sources, θ, such that the carbon dynamics are,

(3) $\dot{C} = \theta C - \delta F + \gamma A,$

where $\dot{C}$ is the change in carbon stock in the atmosphere over time, δ is that rate at which forest biomass sequesters carbon dioxide and γ is the contribution of agricultural production to carbon dioxide emissions. Greenhouse gas emissions can occur from deforestation and agricultural

---

[2] Since we consider a dynamic model, each variable is indexed by time t. To reduce notation clutter, we suppress the index t for now.

[3] Subscripts on functions denote derivatives, $\frac{dF}{dx} = F_x$ and $\frac{d^2F}{dx^2} = F_{xx}$.

production.[4] However, agricultural production may also lead to a positive carbon sequestration from plant growth. Thus, γ may be positive indicating a net increase in carbon dioxide emissions or negative indicating a net increase in carbon sequestration from agricultural production.

Manufacturing output is primarily dependent on labor employed in the sector. The corresponding production function is,

(4) $Y^M = Y^M(L^M, g)$

where L^M is labor employed in the manufacturing sector. We assume production in the sector is increasing and concave in labor and g complements labor such that $Y^M_{L^M g} > 0$. Also the price of output from manufacturing is normalized to 1.

Since the farmer does not internalize the dynamics of carbon and forest stock, we can analyze the behavior of agents one period at a time. During each period of time, t, there are two stages. First, the farmer decides how much forest land to clear given the government's choice of public expenditure allocation. Next, given, the amount of forest land cleared, the farmer purchases capital and labor is allocated across the two sectors of the economy. We solve for the subgame perfect Nash equilibrium in each time period in this two-stage complete information game using backward induction.

2.2 Solution through backward induction

We start with stage 2 where the labor is allocated and the farmer purchases capital given public expenditure levels and the amount of forest land cleared. The following equations solve the general equilibrium model,

(5) $pY^A_{L^A}(K, L^A, F, A; g, x) = w$

(6) $Y^M_{L^M}(L^M, g) = w$

[4] Globally, greenhouse gas emissions from forest land clearing account for 17% of global greenhouse gas emissions while agriculture accounts for 14% (IPCC, 2007).

(7) $Y_K^A(K, L^A, F, A; g, x) = r$

(8) $L^A + L^M = \bar{L}$

where $\bar{L}$ is the aggregate labor in the economy, p is the relative price of the agricultural output, w is an endogenous wage rate and r is an exogenous price of capital. We find that when farmers commit to more land clearing, there is an increase in capital and labor in the agricultural sector, a decline in labor in the manufacturing sector and an increase in wages (See Appendix A for proof). Thus, an increase in forest land clearing for agricultural production leads to an increase in output in the agricultural sector and a decline in the manufacturing sector.

Government spending has a direct effect on capital and labor choice but there is also an indirect effect through the amount of forest land cleared for agricultural production. The direct effect of g and x on inputs is ambiguous (See Appendix A for proof). Given the assumption that x and K are substitutes, a rise in x directly reduces the amount of capital purchased but a countervailing effect occurs where K increases because we assume capital and labor are complements and labor increases with x. Furthermore, a rise in g increases marginal production in both sectors. We will only be able to determine the direction by which g affects inputs if we assume that the impact of g is larger in one sector than the other.

Our focus is to determine the indirect effect of government spending through forest land clearing for agricultural production in stage 1. In stage 1, the optimum level of forest land cleared is chosen. Given the open access nature of the forest resource stock, land is cleared until aggregate profits are equal to zero,

(9) $\pi(A) = pY^A(K^*, L^{A*}, F, A; g, x) + w(\bar{L} - L^{A*}) - rK^* - c(g)A = 0,$

where $c(g)$ is the cost of forest land clearing and w, K^* and L^{A*} are both functions of $A, x, g, r, \bar{L}$ and F. Here, we assume that $c_g > 0$.

The decision of farmers to clear forest land for agricultural production is fully governed by (9) since they do not internalize the dynamics of (2) and (3) such that,

(10) $$A^{*} = H(F, g, x, p, r, \overline{L}).$$

When profits are positive, more forest land is cleared until the rents from the resource stock are dissipated.

In each time period, a subgame perfect Nash equilibrium exists when:

1. Farmers clear forest land for agricultural production until equation (9) is met; and
2. Labor is allocated across both sectors, wage is determined by the market and capital is purchased by farmers as shown by equations (5) to (8).

Figure 1 illustrates the trajectory and steady-state levels of forest biomass and forest land clearing under open access in our framework. The forest stock dynamics isocline, $\dot{F} = 0$, is an upward sloping line starting at the origin with a slope α/β. At any point above $\dot{F} = 0$, forest stock decreases while below it forest stock increases. Also, $\pi(A^{*}) = 0$ governs the amount of forest land to clear for agricultural production in every time period. It is positively sloped because, $\frac{dA}{dF} = -\frac{\pi_F}{\pi_A} = -\frac{pY_F^A}{pY_A^A - c}$. The sign hinges on the denominator of the equation.

Under open access, the denominator is negative because resource rents are dissipated. At F(0), forest land clears at A(0). As more forest land is cleared for agricultural production, the forest biomass stock declines which reduces the value of marginal product in the agricultural sector. This leads to a shift in labor away from the agricultural sector towards the manufacturing sector leading to a reduction in forest land clearing. Since we are above $\dot{F} = 0$, there is a movement along $\pi(A^{*}) = 0$ down and to the left until the steady-state forest land clearing for agricultural production at A^{ss} and forest stock at F^{ss}.

2.3 The effect of fiscal spending on forest cover and carbon dioxide emissions

Government expenditures affect the steady-state level of cleared forest land for agricultural production as well as the trajectory path towards the steady state through their direct effects on production and the marginal cost of land clearing. The effect of *g* on profits is such that $\pi_g = pY_g^A(K^*, L^{A*}, F, A^*; g, x) - c_g(g)A^*$. There are two countervailing effects of public goods expenditure on profit in the agricultural sector. Any increase in *g* increases the marginal cost of forest land clearing as more protection for the environment is in place. However, investment in agricultural research and development and public infrastructure such as roads increases the value of marginal product of agriculture. When the latter effect outweighs the former effect, the iso-profit line shifts up, otherwise it will shift down.

When total government spending, *G*, rises, there is an additional contribution to the value of marginal product of agriculture through an increase in x. Here, the iso-profit line is more likely to shift up since $\pi_G = \pi_x + \pi_g = p\left(Y_g^A + Y_x^A\right) - c_g(g)A^*$. Thus, it is more likely that we see a short-run increase in forest land clearing for agricultural production but a lower steady-state level of forest land cleared in the long run. Fan and Zhang (2008) provide empirical support showing that there is a significant rise in marginal productivity in agriculture from Uganda as government spending targeted in extension and research and development increases.

At the initial steady-state forest stock, F^{ss}, forest land is cleared for agricultural production at A^{ss} as illustrated in Figure 1. A rise in *G* increases the value of marginal product of agriculture and marginal cost of land clearing for any given level of forest stock. If the former effect outweighs the latter effect, the iso-profit line will shift up from $\pi \quad = 0$ to $\pi^G = 0$. In the short run, this will cause an instantaneous increase in forest land cleared for agricultural production leading to a reduction in the forest biomass. The trajectory follows $\pi^G = 0$ down and to the left because as *F* is reduced, the value of marginal product declines leading to less forest land cleared. In the long run, a lower steady-state stock is reached at F^{ss1} along with a lower steady state cleared forest land at A^{ss1} compared to the initial steady state.[5]

Figure 2 illustrates the impact of *G* on carbon stock levels where agricultural production leads to a net decline in carbon dioxide emissions, i.e. $\gamma < 0$. In (*C,A*) space, equation (9) is drawn as a horizontal line because $\frac{dA}{dC} = -\frac{\pi_C}{\pi_A} = 0$ since $\pi_C = 0$. The carbon stock isocline, $\dot{C} = 0$, is upward sloping with a slope of $\frac{dA}{dC} = \frac{\theta}{\delta\frac{dF}{dA} - \gamma}$ since $\frac{dF}{dA} > 0$ and $\gamma < 0$.[6] To the right of the isocline, carbon dioxide emissions increase and to the left carbon dioxide emissions are reduced. Assuming an initial steady-state level of agricultural production at A^{ss}, it is not clear if carbon dioxide emissions are increasing, decreasing, or not changing. Solving for the steady-state forest stock as a function of steady-state agricultural production, we find that there is no change in carbon stock when $C = \left(\frac{\delta\beta - \gamma\alpha}{\alpha\theta}\right) A^{ss}$. A higher carbon stock than this will increase carbon dioxide emissions while a lower level will decrease it.

An increase in *G* will shift the profit line to $\pi^G(A^G) = 0$, implying more forest land is cleared for agricultural production, when the value of marginal product is higher than the marginal cost of land clearing.[7] This results in a larger segment by which carbon dioxide emissions can decline in the short run. Intuitively, this is because more agricultural production has the potential to yield a net increase in carbon sequestration. However, as the forest biomass is depleted and labor moves toward the manufacturing sector, agricultural production steadily decreases until the new steady state at $\pi^{ss1}(A^{ss1}) = 0$. Here, the segment representing a

[5] If the marginal cost of land clearing has a greater effect than the rise in the value of marginal product of agriculture, the iso-profit line shifts down and the opposite effects occur.
[6] Note that when $\gamma > 0$, $\dot{C} = 0$ is still upward sloping for higher levels of carbon but there may be a downward sloping region at low levels of carbon.
[7] If the marginal effect of *G* on the value of marginal productivity of agriculture is less than the marginal cost of land clearing, then the iso-profit line shifts down instead and the opposite results hold.

potential for decline in carbon dioxide emissions is smaller in the long run due to a lower forest biomass stock and a lower steady-state level of agricultural production.

III. Empirical Model

We determine the effect of government spending on forest cover and deforestation-induced carbon emissions in three stages. First, we estimate the effect of government spending on forest land clearing for agricultural production and derive the corresponding elasticity. Next, to derive the total effect of government spending on forest cover change, we combine our elasticity estimates in stage 1 with estimates from micro studies relating the effect of forest land clearing on forest cover. Finally, we simulate the change in carbon dioxide emissions given a change in government spending from the elasticity of forest cover.

3.1 Deriving the effect of government spending on forest land clearing for production of agricultural crops

We measure the effect of expenditures on public goods for forest land clearing by estimating an empirical model where a discrete form of (2) is substituted into (10). Successive substitutions of (2) yields,

$$(11) \qquad F_t = \left(\frac{1}{1-\alpha}\right)^t F_0 - \beta \sum_{n=0}^{t} \left(\frac{1}{1-\alpha}\right)^{n+1} A_{t-n} = F(F_0, A_t, A_{t-1}, A_{t-2}, \ldots)$$

where F_0 is the initial forest stock and A_{t-n} is lagged forest land clearing for agricultural production. Divide and multiply g and x by G, where $G \equiv g+x$ is total government spending, and then normalize G by consumption per capita, c. Using (11) into (10), along with the above simplifications and solving for A_t yields,

$$(12) \qquad A^*_t = H(s, 1-s, \bar{G}, p, r, \bar{L}, F_0, A_{t-1}, A_{t-2,\ldots}),$$

where $s \equiv g/G$ is the share of expenditures of public goods relative to total government spending and $\bar{G} \equiv G/c$ is the share of government spending relative to the total size of the economy.

From (12) we derive the following empirical relationship,

$$(13)\ \ln A_{it} = \alpha_1 \ln s_{it} + \alpha_2 \ln \bar{G}_{it} + \alpha_3 \ln p_{it} + \alpha_4 \ln r_{it} + \alpha_5 \ln \bar{L}_{it} + \alpha_6 \ln F_{0i} + \sum_{n=1}^{X} \alpha_{6+n} \ln A_{it-n} + \varepsilon_i + \sigma_t + \mu_{it},$$

where subscripts i and t represent country and time, respectively and α_j (j=1,..,X) are fixed parameters. Thus, A_{it} and A_{it-n} are the amount of agricultural land cleared from forest land in country i at year t and $t-n$, respectively; s_{it} is the share of public goods expenditure in country i at time t; $\bar{G}_{it}$ is government consumption expenditure over GDP; p_{it} is an index of agricultural crop prices planted in cleared forest land in country i at year t; r_{it} is the price of investment in country i at year t; $\bar{L}_{it}$ is the labor force in country i at year t; F_{0i} is the land area of the country which is a proxy for the initial forest biomass; ε_i is a country effect which can be fixed or random; σ_t is a time effect common to all countries; and μ_{it} is a random disturbance with the usual desirable properties.

To determine if the share of expenditures on public goods and aggregate government spending increases forest land clearing in the short run, we determine if α_1 and α_2 are positive and significantly different from zero, respectively. The long-term effect of these variables are calculated using the formula $\frac{\alpha_1}{1-\sum_{n=1}^{X} \alpha_{6+n}}$ and $\frac{\alpha_2}{1-\sum_{n=1}^{X} \alpha_{6+n}}$ for the share of expenditures on public goods and aggregate government spending, respectively.

A few notes regarding the estimation of (13) are in order. First, estimation of a dynamic panel lagged model requires the use of generalized method of moments to obtain consistent estimates given a fixed sample size (Arellano and Bond, 1991). Next international shocks may have common effects across countries such as changes in the international interest rate that could affect all countries. We use time dummies to capture the effect of this variable. Also, there are many unobserved characteristics of countries which we capture using fixed or random effects. Finally, endogeneity may affect the fiscal spending variables and the crop price index because they may be affected by forest land cleared. We test formally for endogeneity of the crop price index using a Hausman test with annual precipitation as an instrument since rainfall could affect the value of production and, therefore, its price but rainfall is unlikely correlated with forest degradation directly. We fail to reject the null hypothesis of exogeneity.[8] To avoid any potential endogeneity with fiscal spending, we use lagged size of government spending and lagged share of public goods expenditure instead of current levels.

3.2 The effect of government spending on forest cover and carbon dioxide emissions

The total effect of fiscal policies on forest cover is derived by multiplying the elasticity from (13) with the elasticity relating forest land clearing to forest cover in (11). The short-run and long-run effects of the share of expenditures on public goods and aggregate government spending on forest cover are,

(14) $\epsilon_k^{Fs} = \epsilon_A^{Fs}\alpha_k$ and $\epsilon_k^{Fl} = \epsilon_A^{Fl}\frac{\alpha_k}{1-\sum_{n=1}^{X}\alpha_{6+n}}$ for k =1,2,

where k = 1 represents the effect of the share of public goods expenditures and, k = 2 represents the aggregate government spending. Furthermore, $\epsilon_A^{Fs} \equiv -\frac{\beta}{1-\alpha}\frac{A}{F}$ and $\epsilon_A^{Fl} \equiv \frac{\beta}{\alpha}\frac{A}{F}$ are the short-run elasticity and long-run elasticity, respectively, of forest land clearing for agricultural production on forest cover.

[8] Precipitation data was taken from the Tyndall Centre for Climate Change Research available at: http://www.cru.uea.ac.uk/~timm/cty/obs/TYN_CY_1_1.html.

Through successive substitutions of (3), we find that the current carbon sequestration level is equal to,

(15) $$C_t = \left(\frac{1}{1-\theta}\right)^t C_0 - \delta \sum_{n=0}^{t} \left(\frac{1}{1-\alpha}\right)^{n+1} F_{t-n} + \gamma \sum_{n=0}^{t} \left(\frac{1}{1-\alpha}\right)^{n+1} A_{t-n},$$

where C_0 is the initial carbon stock and F_{t-n} are lagged forest levels. Thus, the short-run and long-run elasticities illustrating the effect of a change in the fiscal policies on carbon emissions are equal to,

(16) $$\epsilon_k^{Cs} = \epsilon_F^C \epsilon_k^{Fs} + \epsilon_A^C \alpha_k \quad \text{and } \epsilon_k^{Cl} = \epsilon_F^C \epsilon_k^{Fl} + \epsilon_A^C \frac{\alpha_k}{1-\sum_{n=1}^{X} \alpha_{5+n}} \quad \text{k =1,2}$$

where ϵ_k^{Cj} for j = s, l are the short-run and long-run elasticities of carbon sequestration with respect to the government spending variables *k = 1,2*; $\epsilon_F^C \equiv \frac{\delta}{1-\alpha} \frac{F}{C}$ is the elasticity of carbon with respect to forest cover; and, $\epsilon_A^C \equiv \frac{\gamma}{1-\alpha} \frac{A}{C}$ is the elasticity of carbon with respect to agricultural production.

IV. Data

We collect data to estimate the determinants of forest land clearing for agricultural production in (13) and gather parameter estimates to derive the effects of government spending on forest cover and carbon dioxide emissions in (14) and (16).

4.1 Determinants of forest land clearing for agricultural production

We compile an unbalanced panel data set of countries from 1990 to 2003 that have a significant amount of forest cover based on a criteria developed by López et al. (2002). We focus only on countries where forest land clearing is primarily driven by agricultural land use. This narrows our sample of countries to Latin America where there is a prevalence of slash and burn agriculture and pasture conversion practices (Houghton et al., 1991), and Asia, especially in Southeast Asian countries, due to shifting cultivation in mountainous regions (Rerkasem et al., 2009).[9] Appendix B lists the twelve countries in our sample along with crops that we identify as encroaching on forest land based on our survey of studies.

We present the descriptive statistics used in deriving the determinants of forest land clearing in Table 1. There are two key variables in our study. First, we calculate our own measure of forest land cleared for agricultural production. To do so, we identify the primary crops growing near forest land and classify it as a crop encroaching on forest land only if there is a study or report identifying it as such. Based on this literature search, we derive the total amount of agricultural land planted for each crop that we identify as encroaching on forest land from the FAO and add up the total land area planted for all these crops. We use this measure to represent the amount of forest land cleared to produce agricultural crops. Unlike other studies that use the total amount of land harvested, we avoid overestimating the effect of this variable on forest cover by focusing only on crops that are planted in previously forested areas.

The second key variable is a measure of government spending. We use two measures. First, government consumption expenditure data over GDP is used to proxy aggregate spending and is obtained from the Government Financial Statistics database compiled by the International Monetary Fund (IMF). We use data from the Asian Development Bank to supplement the IMF data for some Asian countries. We create our own measure of the composition of expenditures on public goods in total government expenditures by adding up all the subcategories for such expenditure and dividing it by the aggregate government spending variable. Expenditures on public goods include spending in education, health, social welfare, transport, communications, public order and safety, research and development, environment, recreation and culture, and social housing.

---

[9] We excluded countries from Africa and developed countries because the main driver of deforestation in the former was the collection and consumption of fuelwood as a source of energy (Cline-Cole et al., 1990) and urban development in the latter (EEA, 2006).

Other variables in our regression are the crop price index, price of capital investment, rural labor force and land area. We derive the two latter variables from the World Bank database while the price of capital is from the Penn World Tables. We calculate the crop price index from the set of selected crops using the Laspeyres index formula. Rural labor force is proxied by rural population. Appendix C summarizes the sources for our data.

4.2 Forest Cover and Carbon Sequestration Elasticities

We summarize the parameters used in our study in Table 2. To make our estimates comparable with the parameter estimates of micro studies derived from different countries, we adjust the elasticity of forest land clearing for agricultural production on forest cover. First, we use the implied marginal effects from the studies we selected and then calculate the elasticity of forest land clearing on forest cover using the implied marginal effects along with the average forest cover and average area of forest land cleared in our sample.

The short-run and long-run effects of forest land clearing for agricultural production on forest cover came from two studies. The short-run effect of crop area on forest cover was taken from López (2000) who estimated the effect of cultivation on forest clearing in rural villages in Western Ivory Coast using GIS data. He found that a one hectare increase in area cultivated resulted in 4.4 hectare decrease in forest cover because the conversion of forest cover to agricultural land also requires additional clearing for human settlement and infrastructure supporting agricultural production. [10] The long-run effect is taken from Maertens et al. (2006). They found that one hectare of shifting cultivation in Indonesia from 1980-2001 led to an implied marginal effect of 0.88 hectares of reduced forest cover because abandoning the area could have led to some re-growth of natural forest vegetation.

[10] The implied marginal effect of crop area on forest cover in the Ivory Coast is similar to those derived by Osgood (1994) in Indonesia (4.25) and by López (1997) in Ghana (3.9) but it was difficult to accurately calculate the standard errors from these two studies.

There are two mechanisms by which government spending affects carbon dioxide emissions. The first is through the change in forest biomass. We use the conversion coefficient formula from Naughton-Treves (2004) which relates the amount of carbon dioxide emissions, ψ, to the aboveground live forest biomass. Here, $\psi = \lambda \cdot \theta \cdot \rho$, where λ is aboveground live biomass of forest in megagrams per hectare (Mg/ha); θ is the CO_2 fraction of dry biomass; and ρ is the burning efficiency of forest clearance, which refers to the percentage of heat content in the wood that can be extracted and used. The parameters for primary and secondary forests differ as shown in Table 2.

The second mechanism where government spending affects carbon dioxide emissions is through agricultural production. Cropping systems significantly affect the level of carbon dioxide emitted or sequestered during the production process. Samarawickrema and Belcher (2005) simulate that under conventional tillage, there is about 2 tCO_2e/ha/year carbon sequestered and 0.9 tCO_2e/ha/year of emissions leading to a net intake of carbon equal to 1.1 tCO_2e/ha/year. In contrast, under no tillage there is 2.9 tCO_2e/ha/year carbon sequestered and 0.9 tCO_2e/ha/year of emissions leading to a net intake of carbon equal to 2 tCO_2e/ha/year.

V. Empirical Results

To determine the total effect of government spending on deforestation-induced carbon dioxide emissions, we first present our regressions results deriving the determinants of forest land clearing for agricultural production and then combine the elasticities with parameter estimates from the literature.

5.1 Determinants of forest land clearing for agricultural production

We present Ordinary Least Squares (OLS), Fixed Effects (FE), Random Effects (RE) and Generalized Method of Moments (GMM) that estimate equation (13) in Table 3. We calculate standard errors robust to autocorrelation and heteroskedasticity. We find that lagged forest land cleared for agricultural production is significant in all the GMM models and is significant only after one period. Here, a 1% increase in agricultural land expansion in the previous period increases current agricultural land expansion by a similar magnitude. Thus, omitting lagged agricultural land expansion in our model would bias our estimates such as those presented in OLS, FE and RE.

In the models that do include lagged forest land clearing, we find that the effects of our two fiscal policy variables are consistent with our theoretical model. The share of expenditures on public goods has a positive effect on forest land clearing but insignificant in all GMM models. Our model can explain this by pointing to two countervailing effects from expenditures on public goods where it can increase the value of marginal product of agricultural output but it can also raise the marginal cost of land clearing. Based on our estimates, the two effects may offset each other leading to an insignificant effect of the share of government expenditure on public goods.

In contrast, the share of aggregate government expenditure relative to GDP is consistently positive and significant. When government expenditure over GDP increases by 10%, we find that forest land clearing rises by approximately 2%. Again, our theoretical model provides some intuition as to why we obtain such an estimate. Increased government spending not only raises expenditures on public goods but it also increases expenditures on private goods as well which together contributes to a further increase in the value of marginal product of agriculture. The net increase in value of marginal product from both types of spending may outweigh the rise in marginal cost of land clearing from expenditures on public goods alone leading to an influx of labor in the agricultural sector and an increase in agricultural land clearing in the short run.

Table 4 compares the short-run effects of fiscal spending from their long-run effect. We find that the long-run effect of the share of expenditures on public goods is still insignificant. However, the long-run effect of the share of government expenditure relative to GDP is significant and negative which implies that the steady-state level of cleared forest land does decline due to higher amounts of land cleared for agricultural production at each level of forest biomass during the transition period. This is consistent with our theoretical findings illustrated in Figure 1.

5.2 Effect of fiscal policies on forest cover and deforestation–induced carbon emissions

Using Equation (14), we calculate the effect of fiscal policies on forest land by combining our estimates in the GMM with time dummies specification in Table 3 with those from the literature in Table 2. The composition of government expenditure continues to have no significant effect on forest land in the short run and the long run. However, the share of government expenditure relative to GDP significantly reduces forest land in the short run. Also, since the steady-state level of forest land clearing is lower, the long-run effect of government expenditure over GDP reduces steady-state forest cover even further. Here, the effect of government expenditure is significantly larger in the long run than the short run. Thus, there is a lingering and detrimental effect of government expenditure on forest cover not only in the short run but also in the long run.

We determine the effect of changes in government spending for Brazil, the country with the largest forest area in our sample. The average share of government expenditure relative to GDP for Brazil is 26%. The country with the highest share of government expenditure in our sample is Nicaragua at 37%. If Brazil would steadily increase the share of government expenditure relative to GDP at the same level as Nicaragua, our estimates predict an immediate decline in forest biomass by 0.6%. In the long run, the effects are more dramatic since steady-state forest biomass declines by 4%.

We also derive the short-run and long-run effects of fiscal policy size and composition on carbon dioxide emissions. Similar to our previous analysis, it is the aggregate government spending relative to GDP that matters and not the composition of government spending. We find that both short-run and long-run effects tend to increase carbon dioxide emissions but the effect is larger in the latter than the former which is consistent with our results in Figure 2. This is because in the short run, when agricultural production increases, there is also a net increase in carbon dioxide emissions which partially negates the carbon dioxide emissions when forest biomass is cleared. However, in the long run, both the forest biomass stock and agricultural production is reduced which both contribute to a net release in carbon dioxide emissions. In fact the long-run elasticities of carbon dioxide emissions due to government expenditures are almost 14 times larger than the short-run effect.

Our results are in contrast to those found by Lopez et al. (2011) when they investigated the effect of expenditure composition and expenditure levels on production pollutants from dirty manufacturing firms. They found that changing the composition of government spending towards expenditures on public goods significantly reduced pollutants such as sulfur dioxide, lead and biological oxygen demand while government consumption expenditure has no significant effect. In contrast, deforestation-induced carbon dioxide emissions are affected by aggregate government spending relative to GDP but not by the composition of government spending. This result is attributed to the differences in the mechanisms by which the size and composition of government spending affect the production pollutants versus deforestation-related pollution. In our case, countervailing effects of expenditures on public goods lead to an insignificant effect on forest land clearing for agricultural production. However, when aggregate government spending rises, implying an increase in both public and private goods expenditures, the value of marginal product of agriculture increases resulting in more demand for agricultural land, which reduces forest cover and increases carbon dioxide emissions.

VI. Conclusion

This article presents a theoretical and empirical model linking the mechanisms by which the size and composition of fiscal policies affect forest cover and deforestation-induced carbon dioxide emissions. We have shown that the composition of government expenditure does not have any effect on forest land clearing for agricultural production which implies that it also does not have any effect on deforestation-induced carbon dioxide emissions. Our theoretical model provides a plausible explanation to this result. Countervailing effects of expenditures on public goods may occur such that an increase in the marginal cost of land clearing, which reduces forest land clearing, is offset by a rise in the value of marginal product of agriculture, which has an opposite effect on forest land clearing.

In contrast, aggregate government spending induces forest land clearing for agricultural production thereby increasing deforestation-induced carbon dioxide emissions in the short run. Since there is lower steady-state forest biomass and lower steady-state agricultural production, the long-run carbon dioxide emissions rise when government spending increases. Again, our theoretical model shows that increased government spending increases the value of marginal product and may outweigh the higher marginal cost of land clearing leading to more forest cleared for agricultural production.

The results have important policy implications especially during times of recession when developing countries employ countercyclical spending policies that increase the share of government spending in total GDP. Even though aggregate government spending does not have any significant effect on production-based pollutants (Lopez et al. 2011), we show that it has significant negative consequences in terms of land use change and increased deforestation-induced carbon dioxide emissions. This does not mean that we are advocating against policies that increase the size of the government spending during times of recessions. In fact, based on our theoretical framework, one way to mitigate an increase in deforestation-induced carbon dioxide emissions due to an increase in the size of government spending is to have more targeted spending that protect natural resource stocks by enforcing property rights and dissuading forest land clearing especially during times of recession.

References

Antle, J.M. and G. Heidebrink. 1995. Environment and development: theory and international evidence. Economic Development and Cultural Change 43 (3), 603–625.

Bernauer, T. and V. Koubi. 2006. "States as providers of public goods: how does government size affect environmental quality?" Available at SSRN: http://ssrn.com/abstract=900487.

Bulte, E.H., R. Damania and R. Lopez. 2007. "On the gains of committing to inefficiency: Corruption, deforestation and low land productivity in Latin America." Journal of Environmental Economics and Management 54 (3), 277-295.

Chomitz ,K. and T. Thomas. 2003. Determinants of land use in Amazonia: a fine-scale spatial analysis. American Journal of Agricultural Economics 85 (4), 1016–1028.

Cline-Cole, R.A., H.A.C. Main, and J.E. Nichol. 1990. On fuelwood consumption, population dynamics and deforestation in Africa. World Development 18 (4), 513-527.

Cropper, M. and C. Griffiths. 1994. The interaction of population growth and environmental quality. American Economic Review 84 (2), 250–254.

Cropper, M., J. Puri, and C. Griffiths. 2001. Predicting the location of deforestation: the role of roads and protected areas in North Thailand. Land Economics 77, 172–186.

Crutzen, P.J. and M.O. Andreae. 1990. Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. Science 250 (4988), 1669-1678.

European Environment Agency (EEA). 2006. Urban sprawl in Europe: the ignored challenge. EEA Report No. 10. Copenhagen. Available at: http://www.eea.europa.eu/publications/eea_report_2006_10/eea_report_10_2006.pdf.

Fan, S. and X. Zhang. 2008. Public expenditure, growth and poverty reduction in rural Uganda. African Development Review 20(3), 466–496.

Frankel, J., C.A. Vegh , and G. Vuletin. 2011. Fiscal policy in developing countries: escape from procyclicality. Available at: http://www.voxeu.org/article/how-developing-nations-escaped-procyclical-fiscal-policy.

Galinato, G.I. and S.P. Galinato. 2012. The effects of corruption control, political stability and economic growth on deforestation-induced carbon dioxide emissions. Environment and Development Economics 17(1), 67-90.

Galinato, G.I. and S.P. Galinato. 2013. The short-run and long-run effects of corruption control and political stability on forest cover. Ecological Economics 89, 153-161.

Halkos, G. and E. Paizanos. 2013. The effect of government expenditure on the environment: an empirical investigation. Ecological Economics 91, 48-56.

Houghton, R.A., D.S. Leftwowitz, and D.C. Skole. 1991. Changes in the landscape of Latin America between 1850 and 1985: I. Progressive loss of forests. Forest Ecology and Management 38, 143–172.

Intergovernmental Panel on Climate Change (IPCC). 2007. IPCC Fourth Assessment Report: Climate Change 2007. Available at: http://www.ipcc.ch/publications_and_data/ar4/syr/en/spm.html.

López, R.1997. Environmental externalities in traditional agriculture and the impact of trade liberalization: the case of Ghana. Journal of Development Economics 53 (1), 17–39.

López, R., 2000. Trade reform and environmental externalities in general equilibrium: analysis for an archetype poor tropical country. Environment and Development Economics 5 (4), 377–404.

López, R. and G.I. Galinato. 2007. Should governments stop subsidies to private goods? Evidence from rural Latin America. Journal of Public Economics 91, 1071-1094.

López, R. and G.I. Galinato. 2005. Trade policies, economic growth, and the direct causes of deforestation. Land Economics 81 (2), 145-169.

López, R. and A. Palacios. 2013. Why Europe has become environmentally cleaner: decomposing the roles of fiscal, trade and environmental policies. Environmental and Resource Economics (DOI: 10.1007/s10640-013-9692-5).

López, R., G.I. Galinato, and A. Islam. 2011. Fiscal spending and the environment: theory and empirics. Journal of Environmental Economics and Management 62 (2), 180-198.

Naughton-Treves, L. 2004. Deforestation and carbon emissions at tropical frontiers: a case study from the Peruvian Amazon. World Development 32 (1), 173-190.

Polinsky, A.M. and S. Shavell. 2000. The economic theory of public enforcement of law. Journal of Economic Literature 38 (1), 45–76.

Rerkasem, K., N. Yimyam, and B. Rerkasem. 2009. Land use transformation in the mountainous mainland Southeast Asia region and the role of indigenous knowledge and skills in forest management. Forest Ecology and Management 257 (10), 2035-2043.

Samarawickrema, A.K. and K.W. Belcher. 2005. Net greenhouse gas emissions and the economics of annual crop management systems. Canadian Journal of Agricultural Economics 53, 385–401.

Shafik, N. 1994. Economic development and environmental quality: an econometric analysis. Oxford Economic Papers 46, 757–773.

Southgate, D. 1994. Tropical deforestation and agricultural development in Latin America. In: Brown, K. and D.W. Pearce (eds). The causes of tropical deforestation. University College London Press, London, U.K.

Williams, P., J. Larrison, V. Strokova, and K. Lindert. 2012. Social safety nets in Europe and Central Asia: preparing for crisis, adapting to demographic change, and promoting employability. Europe and Central Asia Knowledge Brief 48, 1-4. The World Bank, Washington, D.C., U.S.A.

Williamson, O.E. 2000. The new institutional economics: taking stock, looking ahead. Journal of Economic Literature 38 (3), 595–613.

Tables

Table 1
Summary statistics of variables.

Variable	Mean	Std. Dev.	Min	Max
Forest land cleared for agricultural production (ha)	2,810,483.00	5,948,092.00	10.00	46,900,000.00
Government consumption expenditure over GDP	0.19	0.07	0.11	0.55
Share of government expenditure in public goods	0.54	0.16	0.21	0.83
Crop price index	46.56	494.83	0.00	9,687.14
Price level of investment	526.30	4,261.64	3.89	54,298.54
Rural population	20,200,000.00	93,700,000.00	0.00	845,000,000.00
Land area (ha)	71,800,000.00	186,000,000.00	2,800.00	933,000,000.00

Table 2
Parameters used in the estimation.

	Forest land[a]	Carbon dioxide emissions	
		Forest land[b]	Agricultural land[c]
Marginal effect of agricultural land clearing			
Short run	4.4 ha		
Long run	0.88 ha		
Carbon conversion coefficients			
Primary forest			
Aboveground biomass (λ)		407 Mg/ha	
CO_2 fraction of dry biomass (θ)		0.5	
Burning efficiency of forest clearance (ρ)		0.4	
Secondary forest			
Aboveground biomass (λ)		36.8 Mg/ha	
CO_2 fraction of dry biomass (θ)		0.5	
Burning efficiency of forest clearance (ρ)		0.6	
Net greenhouse gas emissions (tCO2e/ha/year)			
Conventional tillage			-1.1
No till			-2.0

[a] Short run estimate are taken from Lopez (2000) and the long run estimate is from Maertens et al. (2006).
[b] We derive the burning efficiency estimates from Crutzen and Andreae (1990) and all other parameters are from Naughton-Treves (2004). To obtain the biomass from secondary forest, we multiply the average accumulation of aboveground biomass by the fallow period which Naughton-Treves (2004) assume to be 11.5 Mg C/(ha year) and 3.2 years, respectively.
[c] We use estimates from Table 6 of Samarawickrema and Belcher (2005).

Table 3

The determinants of the log of forest land cleared for agricultural production in South American and Asian countries, 1986-1999.

				Generalized Method of Moments[a]		Generalized Method of Moments[b]	
Variables	OLS[a]	Fixed Effects[a]	Random Effects[a]	1st lag of dep. var.	1st and 2nd lag of dep. var.	1st lag of dep. var.	1st and 2nd lag of dep. var.
Lag of log forest land cleared for agricultural production				1.030***	1.023***	1.027***	0.989***
				(0.020)	(0.128)	(0.022)	(0.116)
2nd lag of log forest land cleared for agricultural production					0.008		0.040
					(0.145)		(0.130)
Lag of log government consumption expenditure over GDP	-3.024 ***	0.632	-3.024***	0.197***	0.199***	0.185***	0.196***
	(0.376)	(0.421)	(0.376)	(0.067)	(0.077)	(0.066)	(0.075)
Lag of log share of government expenditure in public goods	-2.268 ***	-0.234	-2.268***	0.072	0.074	0.062	0.068
	(0.390)	(0.255)	(0.390)	(0.052)	(0.058)	(0.061)	(0.067)
Log of crop price index	0.143 ***	-0.026 **	0.143***	-0.009	-0.009	-0.007	-0.008
	(0.045)	(0.012)	(0.045)	(0.008)	(0.007)	(0.006)	(0.006)
Log of price level of investment	-0.141	-0.379	-0.141	0.144**	0.145**	0.138***	0.142***
	(0.405)	(0.301)	(0.405)	(0.067)	(0.067)	(0.061)	(0.058)
Log of rural population	0.025	0.509	0.025	0.016	0.017	0.015	0.016
	(0.115)	(0.974)	(0.115)	(0.013)	(0.013)	(0.010)	(0.010)
Log of land area	1.284 ***		1.284***	-0.053**	-0.054*	-0.049*	-0.052
	(0.086)		(0.086)	(0.025)	(0.034)	(0.028)	(0.033)
Constant	-15.577 ***	7.599	-15.577***	0.173	0.179	0.068	0.099
	(2.542)	(16.397)	(2.542)	(0.580)	(0.605)	(0.508)	(0.534)
No. of observations	122	122	122	122	122	122	122
No. of groups		12	12	12	12	12	12
No. of instruments				34	34	34	34
Hausman test for overidentification (prob Chi-square)				1.00	1.00	1.00	1.00

*** 5%, **10%, *15%.

[a] With annual time dummies, [b]Without annual time dummies.

Standard errors are in parentheses. Standard errors from the Fixed Effects and Random Effects are calculated using clustered Huber-White standard errors which are robust heteroskedastic-consistent standard error estimates. Standard errors from the Generalized Method of Moments are consistent with panel-specific autocorrelation and heteroskedasticity in one-step estimation.

Table 4
Elasticities of forest land cleared for agricultural production, forest cover and deforestation-induced carbon dioxide emissions from government expenditure.

	Forest Land Cleared for Agricultural Production	Forest Cover	Carbon Dioxide Emissions (Sequestration)		
			Agricultural Production	Forest Cover	Total
Short Run					
Share of government expenditure relative to GDP	0.197*** (0.067)	-0.053*** (0.018)	-0.045*** (0.015)	0.308*** (0.107)	0.263*** (0.091)
Share of expenditures on public goods	0.072 (0.052)	-0.019 (0.014)	-0.017 (0.012)	0.113 (0.081)	0.097 (0.069)
Long run					
Share of government expenditure relative to GDP	-6.635** (3.401)	-0.355** (0.191)	1.531** (0.785)	2.080** (1.119)	3.611** (1.882)
Share of expenditures on public goods	-2.439 (1.870)	-0.130 (0.102)	0.563 (0.432)	0.765 (0.599)	1.327 (1.026)

*** 5%, ** 10%, *15% levels of significance.
We use estimates from the GMM model with annual time dummies for our calculation. Asymptotically, the variance of a nonlinear univariate function, *g(A)*, is equal to $V(g(A)) = \left(\partial g/\partial A\right)^T V(A)\left(\partial g/\partial A\right)$ where $\partial g/\partial A$ is a vector whose i^{th} element is the partial derivative of *g* with respect to the i^{th} element *A,* and *V(A)* is the variance-covariance matrix of the parameters in the vector *A*.

Figures

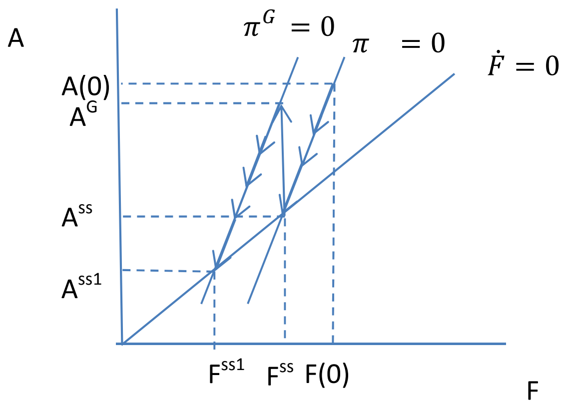

Figure 1. The effect of total government expenditures on forest biomass.

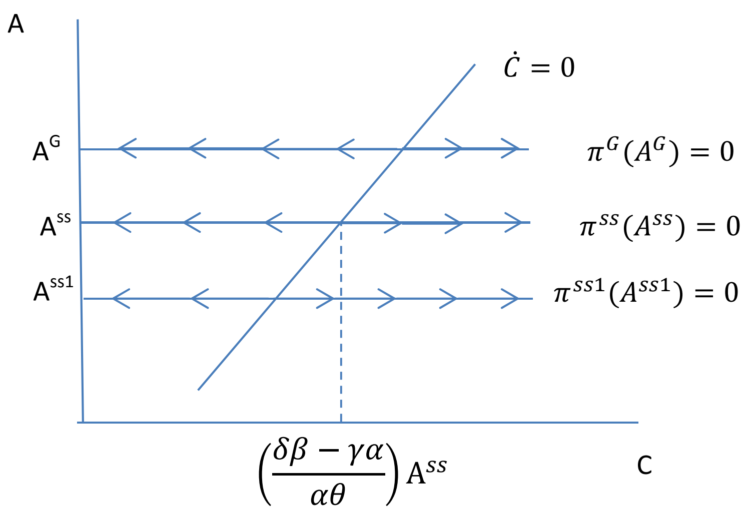

Figure 2. The effect of total government expenditures on carbon stock.

Appendix A. Deriving Comparative Statics.

We can simplify equations (5) to (8) as a system of two equations by equating (5) to (6) and substituting (8) in (6):

(A1) $pY^A_{L^A}(K, x, L^A, F, A, g) - Y^M_{L^M}(\bar{L} - L^A, g) = 0$

(A2) $pY^A_K(K, x, L^A, F, A, g) = r$

Totally differentiating (A1) and (A2) with respect to A yields,

$$\begin{bmatrix} pY^A_{L^A L^A} + Y^M_{L^M L^M} & pY^A_{L^A K} \\ pY^A_{K L^A} & pY^A_{KK} \end{bmatrix} \begin{bmatrix} \frac{dL^A}{dA} \\ \frac{dK}{dA} \end{bmatrix} = \begin{bmatrix} -pY^A_{L^A A} \\ -pY^A_{KA} \end{bmatrix}.$$

Where the 2 x 2 matrix is the Hessian. Using Cramer's Rule, we derive,

$$\frac{dK}{dA} = \frac{-pY^A_{KA}\left(pY^A_{L^A L^A} + Y^M_{L^M L^M}\right) + pY^A_{L^A K} pY^A_{L^A A}}{pY^A_{KK}\left(pY^A_{L^A L^A} + Y^M_{L^M L^M}\right) - pY^A_{K L^A} pY^A_{L^A K}}.$$

The denominator is positive if matrix is negative semidefinite. Since we assume $Y^A_{L^A A} > 0$, $Y^A_{KA} > 0$ and $Y^A_{L^A K} > 0$ then numerator is positive leading to $\frac{dK}{dA} > 0$.

$$\frac{dL^A}{dA} = \frac{-pY^A_{L^A A} pY^A_{KK} + pY^A_{L^A K} pY^A_{KA}}{pY^A_{KK}\left(pY^A_{L^A L^A} + Y^M_{L^M L^M}\right) - pY^A_{K L^A} pY^A_{L^A K}}$$

Denominator is positive if matrix is negative semidefinite. Since we assume $Y^A_{KK} < 0$, $Y^A_{L^A A} > 0$, $Y^A_{KA} > 0$ and $Y^A_{L^A K} > 0$ then numerator is positive leading to $\frac{dL^A}{dA} > 0$. Also, because $\frac{dL^A}{dA} + \frac{dL^M}{dA} = 0$, $\frac{dL^M}{dA} < 0$.

Finally, the effect of A on w can be derived using,

$$Y^M_{L^M L^M} \frac{dL^M}{dA} = \frac{dw}{dA} > 0.$$

We use a similar method to determine the effect of x and g on inputs. We obtain the following comparative statics:

$$\frac{dK}{dx} = \frac{-pY^A_{Kx}\left(pY^A_{L^AL^A} + Y^M_{L^ML^M}\right) + pY^A_{L^AK}pY^A_{L^Ax}}{pY^A_{KK}\left(pY^A_{L^AL^A} + Y^M_{L^ML^M}\right) - pY^A_{KL^A}pY^A_{L^AK}};$$

$$\frac{dL^A}{dx} = \frac{-pY^A_{L^Ax}pY^A_{KK} + pY^A_{L^AK}pY^A_{Kx}}{pY^A_{KK}\left(pY^A_{L^AL^A} + Y^M_{L^ML^M}\right) - pY^A_{KL^A}pY^A_{L^AK}}.$$

The numerators in both comparative statics are now ambiguous because $Y^A_{Kx} < 0$.

Furthermore, the following comparative statics are ambiguous because the numerators contain the term $pY^A_{L^Ag} - Y^M_{L^Mg}$ which may be positive or negative,

$$\frac{dK}{dg} = \frac{-pY^A_{Kg}\left(pY^A_{L^AL^A} + Y^M_{L^ML^M}\right) + pY^A_{L^AK}\left(pY^A_{L^Ag} - Y^M_{L^Mg}\right)}{pY^A_{KK}\left(pY^A_{L^AL^A} + Y^M_{L^ML^M}\right) - pY^A_{KL^A}pY^A_{L^AK}};$$

$$\frac{dL^A}{dg} = \frac{-\left(pY^A_{L^Ag} - Y^M_{L^Mg}\right)pY^A_{KK} + pY^A_{L^AK}pY^A_{Kg}}{pY^A_{KK}\left(pY^A_{L^AL^A} + Y^M_{L^ML^M}\right) - pY^A_{KL^A}pY^A_{L^AK}}.$$

Appendix B. List of countries and agricultural crops encroaching on forest land.

Country	Crop/s
Argentina	Cotton, Maize, Soybeans
Brazil	Banana, coffee, maize, rice, soybeans, cassava/tapioca, beans (including cowpeas and other types)
China	Soybeans
Costa Rica	Banana, mango
Ecuador	Cacao, coffee, manioc/cassava, naranjilla, tea, palm oil, rice, maize
India	Soybeans
Mexico	Maize, commercial chili
Nicaragua	Palm fruit
Panama	Coffee
Philippines	Cassava, corn, rice, sweet potato
Thailand	Cassava
Venezuela, RB	Banana, coffee, maize, tobacco, cassava, sugar cane, citrus fruit

Note: Agricultural crops encroaching on forest land refer to crops identified in studies that are planted along shifting agricultural frontiers converted from forest land. Given space limitations, we do not include here the citations from each individual study that helped us identify these crops. The citations are available from the authors on request.

Appendix C. Definition and sources of variables used in the study.

Variable name	*Definition*	*Source/s*
Forest land cleared for agricultural production (ha)	Total area harvested of crops encroaching on forest land in hectares. Crops that encroach on forest land are identified through a literature survey. The total area harvested for all identified crops are added up. This measure was used to represent the area of forest land cleared to produce agricultural crops.	Author's calculation using data from FAOSTAT – Production[a]
Government consumption expenditure over GDP	General government final consumption expenditure (formerly general government consumption) includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defense and security, but excludes government military expenditures that are part of government capital formation.	Government Financial Statistics (IMF), Asian Development Bank, Country data
Share of public goods expenditure	Public goods in total government expenditures include: education, health, social security, transport, communication, public order and safety, housing and community amenities, environmental protection, religion and culture.	Author's calculation using date from Government Financial Statistics (IMF), Asian Development Bank, Country data
Crop price index	Calculation is based on the Laspeyres index formula: $P = \frac{\sum (p_c t_n \times q_c t_0)}{\sum (p_c t_0 \times q_c t_0)}$ where P is the change in price level, p_c,t represents the prevailing price of crop c in period t, q_c,t is the quantity of crop c sold in period t, t_0 is the base period (year 2000), and t_n is the period for which the index is computed.	Author's calculation using data from FAOSTAT – Production (Crops) database and FAOSTAT - Production (PriceSTAT) database.[a]
Price level of investment	Price level of investment is calculated as the Purchasing Power Parity over Investment divided by the exchange rate times 100.	Penn World Table[b]
Rural population	Rural population refers to people living in rural areas as defined by national statistical offices. It is calculated as the difference between total population and urban population. This variable is used as a proxy measure for rural labor force.	World Bank Data Catalog
Land area (ha)	Land area is a country's total area, excluding area under inland water bodies, national claims to continental shelf, and exclusive economic zones. In most cases the definition of inland water bodies includes major rivers and lakes.	World Bank Data Catalog

[a] Food and Agriculture Organization of the United Nations (FAO). 2009. FAOSTAT – Production (Crops) and Prices (PriceSTAT) databases. Available at: http://faostat.fao.org/.
[b]Alan Heston, Robert Summers and Bettina Aten. 2012. Penn World Table Version 7.1, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania. Available at: https://pwt.sas.upenn.edu/php_site/pwt_index.php.
[c] The World Bank. 2013. Data Catalog. Available at: http://data.worldbank.org/.