Modeling Carbon Leakages with Forestation Policies

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Abstract
This paper analyzes carbon leakage due to reduced emissions from deforestation (RED). We find that leakage with RED is good because the policy induces afforestation that contributes to a further carbon sequestration. By ignoring the domestic component of carbon leakage, the literature can either overestimate or underestimate leakage, depending on the magnitudes of the numerator and the denominator of the leakage formulas. Unlike the literature, we include the land and agricultural markets in the analysis of carbon leakage with forestation policies. In this model, carbon leakage depends on: (1) supply and demand elasticities of timber production and consumption, respectively in the country introducing a RED policy (Home country) and in the rest of the world; (2) Home country's production and consumption share in the world timber production and consumption, respectively; (3) prices of land and crop products in the Home country and the rest of the world; (4) initial allocation of land between forestry and agriculture; (5) share of total forest area set aside under RED; and (6) relative carbon sequestration potential of the forest planted on an afforested land and of the forest withdrawn from timber harvest. These potentials depend heavily on the forest species as well as on timing of the policy, and on the discount rate and time path of increasing carbon prices.

JEL: Q23, Q24, Q54
Key words: carbon leakage, forestry, reduced emissions from deforestation, afforestation

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1. Introduction

Parties to the Kyoto Protocol and successive negotiations on global climate change in Copenhagen and Cancun have been reluctant to expand the use of carbon offsets related to land use and land use change in the forestry and agricultural sectors in order to reduce carbon emissions.[1] One of the primary reasons is 'carbon leakage', i.e., a possibility that emissions are simply shifted to another location or sector as a result of a change in market forces resulting from the economic effects of carbon offsets. Drabik, de Gorter and Just (2010) show carbon leakage has two components: 'market leakage' and 'relative carbon emissions' (or savings in the case of forestation policies). In this paper, we adapt this framework for one forest policy that affects land use and land use change – avoided deforestation – also known as reduced emissions from deforestation (RED). Other "forestation" policies that are not analyzed in this paper include afforestation (AR), reforestation (RF), and forest management (FM). But as we show later, afforestation is a by-product of RED while reforestation is shown to be part of the definition of timber harvest as firms reforest every year to maintain a sustainable harvest given a market price of timber. We do not analyze FM.[2]

We first analyze the market leakage effect of a RED policy, i.e., the changes in timber harvest due to the policy that occur both domestically and internationally. The standard literature on leakages of forestation policies (Murray, McCarl, and Lee 2004; Gan and McCarl 2007; Murray et al. 2009) takes into account only the timber (forestry) market when analyzing carbon leakage. We do the same only to introduce the basic concepts. Later, we nevertheless, provide an alternative definition of leakage that better accounts for the market reactions to forestation policies and reinterprets the meaning of leakage. Then we introduce land market and agricultural market, the latter representing all crop production for human and animal consumption. By ignoring the non-forestry markets, we show the standard literature overestimates leakage for two reasons: (1) market leakage is lower with the land market included and (2) the literature ignores the induced AR by that RED.

With the timber market only, market leakage depends on two sets of market parameters: (1) supply and demand elasticities of timber production and consumption, respectively in the country introducing a RED policy and in the rest of the world and (2) production and consumption share in the world timber production and consumption, respectively of the country introducing RED. When the land and agricultural markets are included, additional factors have an effect on market leakage: prices of land and crop products before the policy, the initial allocation of land between forestry and agriculture, and the share of total forest land set aside under RED.

Carbon leakage with a RED policy depends on domestic and international market leakages but also on the relative carbon sequestration potential of the forest planted on an afforested area and of the forest withdrawn from timber harvest. The relative sequestration potential depends heavily on a forest species (that determines its carbon sequestration profile) as well as on the timing of the policy.

The remainder of the paper is organized as follows. In Section 2, we develop an analytical framework to analyze market leakage with a RED policy. First we consider the timber

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[1] For ease of reference, we use "carbon" to refer to all greenhouse gases emitted or sequestered as a result of a forest policy.
[2] An afforestation policy can be analyzed in a symmetrical way to a RED policy.

market only and then extend the analysis to include the land and agricultural market. Section 3 presents the relation between the carbon leakage and the market leakage and sequestration potential of a forest. We also discuss the role of carbon sequestration profile of a forest species in determining its sequestration potential. Section 4 provides some concluding remarks.

2. Market Leakage due to a RED Policy

Timber Market with No Interactions with the Land Market

Consider an international market for timber as depicted in Figure 1 where the world price of timber P_0 is determined by the intersection of the excess demand curve *ED* of the Home country and the excess supply curve *ES* of the Foreign country.[3] Initially, *a* tonnes of timber are harvested annually in the Home country and *d* tonnes of timber are harvested in the Foreign country. Assume a RED policy is implemented in the Home country that sets aside an area of forest, i.e., timber cannot be harvested on that land for a fixed period of time.[4] This translates into a contraction of the Home timber supply which is depicted as a horizontal shift from *S* to *S'* (in the first panel of Figure 1) by the reduced quantity of timber *Z*.[5] The reduction in annual harvest of distance *ba* occurs provided the world timber price is unaffected by the RED policy. The shortage of timber in the Home country, however, increases the country's excess demand *ED'* which gives rise to a higher world timber price P_1. With a higher market price, timber producers worldwide are incentivized to increase the annual rate of timber harvest. In order to be able to do that, however, they have to plant new forest on *additional* land previously not used in forestry; this activity is called afforestation.[6] This corresponds to the distances *bc* and *de* in Figure 1 and the actual reduction in timber harvest is represented by the distance *ca*.

Following the standard literature, market leakage in absolute terms would be defined only as the distance *de* in the second panel of Figure 1, termed *international leakage*, not taking into account *domestic leakage* of distance *bc* in the Home country. The argument for only considering the international leakage is that the internal response, i.e., domestic leakage, (and carbon emissions related to it) should be captured with a national accounting system and therefore does not constitute leakage (Murray 2008). However, pursuing this argument further, one could also account for the international leakage to achieve a desirable reduction in carbon emissions. Therefore, by not taking into consideration the domestic component of leakage, measures of leakage may be biased.

In Appendix 1, we derive a simple formula for market leakage due to a RED policy when the land market is not considered:[7,8]

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[3] The results of the paper are independent of the country being an exporter or importer.

[4] The length of the period is typically specified in the contract of the project under the Clean Development Mechanism.

[5] The amount of timber that is annually set aside due to a RED policy equals the ratio of land set aside to the total forest area, multiplied by the available amount of timber (per year) prior to the policy.

[6] New forest is also planted on a land that has previously been used for timber production (called *reforestation*) but this replanting is not induced by the policy because it would have occurred also under the business as usual scenario as a part of the optimal rotation of the forest.

[7] All appendices to this paper can be found on the website listed in references.

[8] This formula equally holds for an afforestation (AR) policy.

$$L_M = \frac{\phi\eta_{SH} + (1-\phi)\eta_{SF}}{\phi\eta_{SH} + (1-\phi)\eta_{SF} - \rho\eta_{DH} - (1-\rho)\eta_{DF}} \qquad (1)$$

where ϕ denotes the Home country's share of world timber production; ρ denotes the Home country's share of world timber consumption; and η denotes an elasticity. The first subscript S or D in each term signifies supply and demand, respectively, and the second subscript (H and F) denotes country; hence, e.g., η_{SH} denotes the elasticity of timber production in the Home country.

Decomposing leakage into its domestic L_M^D and international L_M^I component, the relative share of domestic leakage depends on production shares and supply elasticities in both countries, but not on timber demand elasticities as leakage occurs only along the supply curves:

$$\frac{L_M^D}{L_M^I} = \left(\frac{\phi}{1-\phi}\right)\frac{\eta_{SH}}{\eta_{SF}} \qquad (2)$$

Inspection of equation (2) reveals that domestic leakage becomes more important relative to international leakage with both an increase in the Home country's share of world timber production and a higher supply elasticity. Therefore, if timber harvest of a country (or a coalition of countries) represents a substantial share of world timber production, the bias of market leakage estimates when ignoring domestic leakage might be substantial. Likewise, it is the case when the domestic supply of timber becomes more elastic.

Equation (1) is very similar – in structure – to that derived by Drabik, de Gorter, and Just (2010) for market leakage with biofuels due to a tax credit. This similarity allows us to adopt two results of that study for forestation policies: (1) a small country in the world timber market does not always face 100 percent market or carbon leakage and (2) a smaller country can, under some situations, see lower leakage of its forestation policies compared to a larger country.

Interactions with the Land and Agricultural Markets

To keep the analysis tractable, consider the case of autarky for two output markets – the timber and the agricultural market.[9] Production of the outputs requires only one input – land, as depicted in Figures 2a and 2b. The market price of timber P_T is where the demand for timber D_T intersects the timber supply S_T (first panel of Figure 2a); associated with this price is an amount of timber *a*. The intersection of the supply and demand curves, S_A and D_A, respectively, in the second panel of Figure 2a determines the market clearing price P_A that generates *a* units of agricultural crop production (we use the same notation for corresponding points in all three panels in order to show how they are related). The timber and agricultural production compete in the land market as shown by Figure 2b. The curves D_F and D_A represent demand for forestry and agricultural land, respectively, and are implicitly given by the first order conditions of profit maximization for the timber and agricultural sectors. The land market price P_L is where the two demand curves in Figure 2b intersect; the amount of land used for agricultural production L_A is read off from the

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[9] Agriculture is modeled as a composite sector that encompasses all crop production for human and animal consumption.

left to the right, whereas the amount of land allocated to timber production L_T is read off from the right to the left in Figure 3b. Total area of land is fixed.

Assume a policy that reduces emissions from deforestation (RED) by preventing some area of forest to be cut down. Setting aside a part of forest can also be thought of as a corresponding reduction in timber harvest (denoted by Z), as the amount of timber contracts proportionally to the reduction in land set aside (see footnote 5). This is why we begin the analysis by shifting the timber supply curve horizontally to the left in the first panel of Figure 2a. Under the assumption that the timber price does not change, the intended reduction in timber harvest is given by the distance ba in the same panel. However, in order for the market to clear, the timber price has to rise to $P_T{'}$. A higher timber price induces a higher timber harvest; this requires more land, which is depicted by the outward shift of the demand curve for forestry land, $D_F{'}$. The fixed amount of land and stronger competition for it make the land market price increase to $P_L{'}$. In a response, marginal cost of agricultural production increases and the supply curve of agricultural products moves to the left in the second panel of Figure 2a to $S_A{'}$. Akin to developments in the timber market, a higher market price for agricultural production, $P_A{'}$, motivates farmers to obtain more land; hence the outward shift in the demand for agricultural land, $D_A{'}$ in Figure 2b.

The shift in demand for agricultural land completes the first round of market reactions triggered by the RED policy. The mutual interaction of the timber and agricultural markets through the land market results in gradual adjustments of the system that finally converges to a new equilibrium. Let this new equilibrium be characterized by the quantity d in each of the three markets. Now we can evaluate what the market leakage of the RED policy is. When the land (and also agricultural) market is ignored, the market leakage in the timber sector is given by the distance bc in the first panel of Figure 2a (this corresponds to distance bc in Figure 1). The true market leakage, however, is given by the distance bd which is less than bc and is a result of the adjustments among all three markets. Therefore, by looking only at the timber market when evaluating the effects of forestation policies, the literature overestimates the market leakage.

Another outcome of our model is that a RED policy, through an increase in timber prices, induces afforestation. This follows from Figure 2b, where the increase in land allocated to forestry is the distance da and it is positive. Therefore, the market leakage of bd, in the first panel of Figure 2a, corresponds to the new land allocated to forestry – distance da in Figure 2b. Because the total area of land is fixed, agricultural sector loses the same amount of land.

The intuitive explanation of market leakage above is formalized in Appendix 3 that also provides a formula to estimate market leakage of a RED policy under integrated markets:

$$
L_M^T \approx \frac{\dfrac{\alpha}{\eta_{DT}}}{\alpha\left(\dfrac{\gamma}{\eta_{DT}} - \dfrac{1}{\eta_{ST}}\right) + \beta\left(\dfrac{1}{\eta_{DA}} - \dfrac{1}{\eta_{SA}}\right) + \dfrac{\gamma(1-\gamma)}{\eta_{DT}}} \tag{3}
$$

where $\alpha = (P_L L_T)/(P_T q_T)$, $\beta = (P_L L_T)/(P_A q_A)$, $\gamma = R/L_F$, and η denotes an elasticity. In words, α represents a ratio of the cost a timber producing firm pays for renting the land to the revenues from marketing the timber. The parameter β is a ratio of rent for land on which timber is produced to the revenues of the agricultural sector. Finally, the parameter γ denotes a share of land that is set aside in total forestry land.

Equation (3) shows that the magnitude of market leakage of a RED policy, in addition to the parameters α, β, and γ, depends heavily on the assumed supply and demand elasticities in the timber and agricultural markets. Should the formula be extended to an international trade framework, in addition to the Foreign country's parameters that are counterparts of those in equation (3), Home country's consumption and production shares of timber and agricultural products would also be determinants of market leakage.

3. Carbon Leakage

The implication of our analysis so far is that afforestation (AR) is induced by RED and so leakage is "good". This stands in contrast to the leakage with a RED policy analyzed so far in the literature as well as to the leakage with biofuels, where additional carbon emissions may be generated, depending on the type of biofuel policy (Drabik, de Gorter, and Just 2010). The question arises, however, how "good" is the leakage due to RED? Is it possible that leakage is better than no leakage? What does it depend on? To that end, we construct the following measure of carbon leakage with a forestation policy

$$L_C = \frac{\text{deviation from intended reduction}}{\text{intended carbon reduction}} \tag{4}$$

where the deviation equals the difference between the actual and intended carbon savings. If the actual reduction is greater than that intended, leakage is positive by definition; otherwise it will be negative. Negative carbon leakage is normally seen as the outcome and is deemed to be bad.

Denote the initial reduction in timber production by Z. We denote the size of market leakage (now measured in tonnes of timber) in the Home and Foreign country by ΔQ_H and ΔQ_F, respectively. With a RED policy, ΔQ represents both domestic and international afforestation due to an increase in world timber prices. Finally, let e_R denote the sequestration potential of a tonne of timber withdrawn from harvest and let e_A be the sequestration potential of a tonne of timber that grows on an afforested land.[10] Then, following definition (4), carbon leakage with a RED policy is given by

$$L_C^{RED} = \frac{e_A(\Delta Q_H + \Delta Q_F) + e_R(Z - \Delta Q_H) - e_R Z}{e_R Z} = \left(\frac{e_A}{e_R} - 1\right)L_M^D + \frac{e_A}{e_R}L_M^I \tag{5}$$

where L_M^D and L_M^I denote domestic and international market leakage.

The size of carbon leakage with RED depends on two factors: (1) actual sequestration of afforestation relative to the (remaining) sequestration potential of a forest set aside and (2) magnitudes of domestic and international market leakages of RED.

RED is implemented through projects with a pre-specified duration of T years. The sequestration potential of a forest is not constant, but evolves over time as depicted in Figure 3, where we present possible shapes of curves describing cumulative carbon sequestration (dashed

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[10] For simplicity, we assume the sequestration potential per tonne of timber on the afforested land is the same in both countries. The same is assumed for the sequestration potential per tonne of timber withdrawn from harvest. In other words, we assume no "technical" leakage.

line) and incremental sequestration (solid line).[11] The area under the incremental sequestration curve measures the total amount of carbon sequestered over a period of time. When an area of forest is withdrawn from timber harvest, the carbon savings occur as (*i.*) avoided carbon emissions from not harvesting the forest (first panel of Figure 3) and (*ii.*) a continuation of carbon sequestration of that forest (second panel). Therefore, the total carbon savings of reduced timber production per tonne of timber are

$$E_R = \int_0^T S_1(t)\,dt + \int_{t_0}^{t_0+T} S_2(t)\,dt \tag{6}$$

and the average annual savings over the project duration are

$$e_R = \frac{1}{T}\left(\int_0^T S_1(t)\,dt + \int_{t_0}^{t_0+T} S_2(t)\,dt \right) \tag{7}$$

Timber growing on an afforested land (referred to as market leakage in the analysis above) sequesters carbon both directly (third panel) and indirectly (fourth panel) through the land that used to be cultivated by the agricultural sector. The total sequestration of timber on the afforested land is

$$E_A = \int_0^T S_3(t)\,dt + \int_{t_0}^{t_0+T} S_4(t)\,dt \tag{8}$$

with average annual sequestration potential of [12]

$$e_A = \frac{1}{T}\left(\int_0^T S_3(t)\,dt + \int_{t_0}^{t_0+T} S_4(t)\,dt \right) \tag{9}$$

The average annual sequestration potential depends not only on the duration of a RED project, but also on the curvature of the cumulative sequestration curves.

4. Conclusions

The focus of the present paper was on carbon leakage with one of the forestation policies – reduced emissions from deforestation (RED). Our main finding is that leakage with RED is good because the policy induces afforestation that contributes to a further carbon sequestration. This finding is in stark contrast to the current literature on forestation leakages that ignores that RED

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[11] The incremental sequestration curve represents the derivative of the cumulative sequestration curve.

[12] Since the carbon price is expected to rise (see, e.g., de Gorter and Tsur 2010), the amount of carbon saved will have a different social value. Equations (6) - (9) can be modified (Appendix 4) to reflect this. It is very possible that savings from AR are higher than from RED. The third panel of Figure 3 shows higher savings later when carbon prices are higher so one cannot unambiguously compare, for a given discount rate, because of the increasing carbon prices. The result depends on the curvature of the cumulative sequestration curves.

induces afforestation. This is not the only important finding, however. By ignoring the domestic component of carbon leakage, the literature can either overestimate or underestimate leakage, depending on the magnitudes of the numerator and the denominator of the leakage formulas. Yet another advancement of our paper is the inclusion of the land and agricultural market in the analysis of carbon leakage with forestation policies.

In the model integrating all three markets, market leakage depends on: (1) supply and demand elasticities of timber production and consumption, respectively in the country introducing a RED policy (Home country) and in the rest of the world; (2) Home country's production and consumption share in the world timber production and consumption, respectively; (3) prices of land and crop products in the Home country and the rest of the world; (4) allocation of land between forestry and agriculture; and (5) share of total forest area set aside under RED.

Carbon leakage, in addition to above factors, also hinges on the relative carbon sequestration potential of the forest planted on an afforested land and of the forest withdrawn from timber harvest. These potentials depend heavily on the forest species as well as on timing of the policy, and on the discount rate and time path of increasing carbon prices.

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Figure 1: Forestation Leakage with a RED Policy: No Interaction with the Land Market

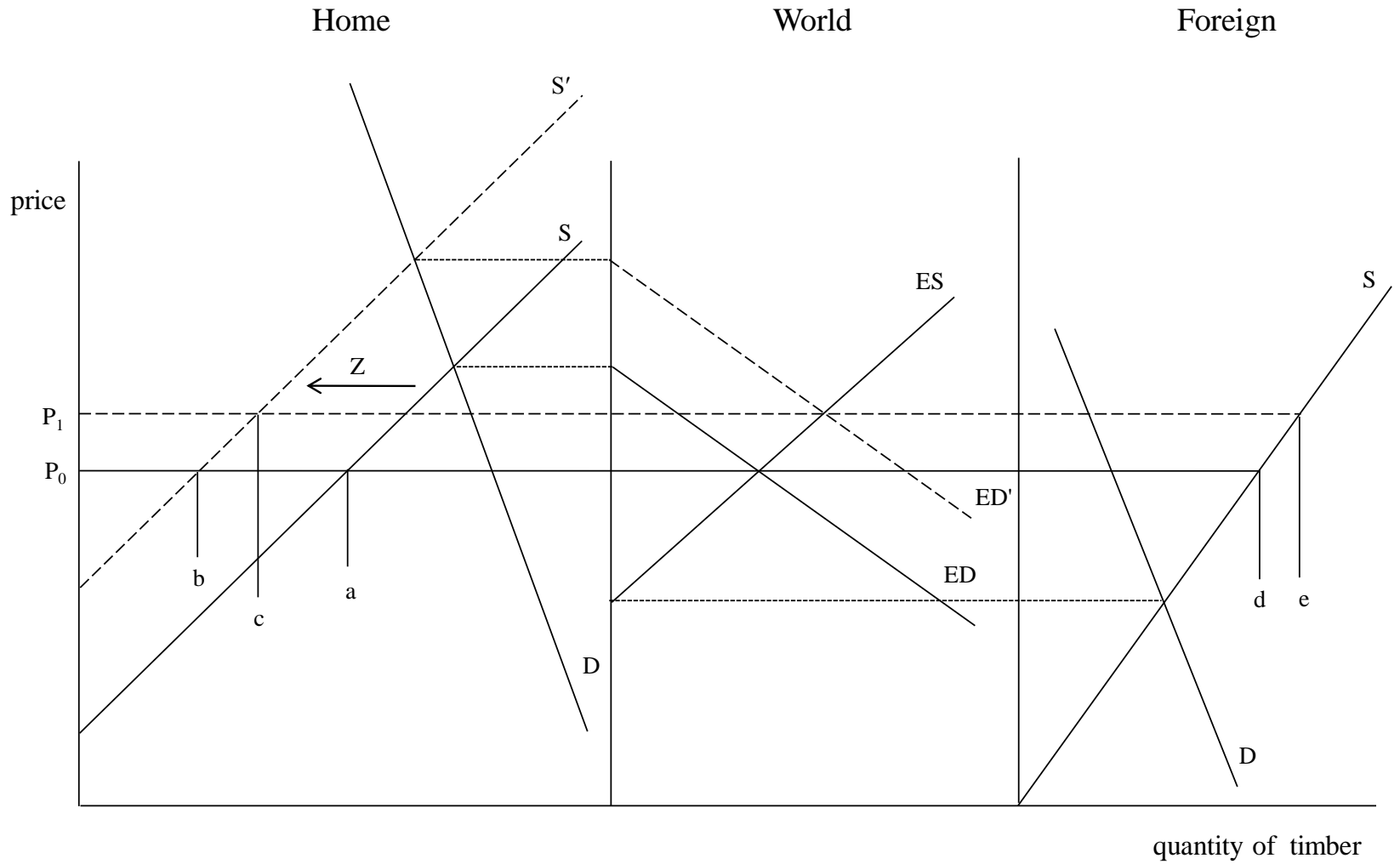

Home   World   Foreign

Figure 2a: Forestation Leakage with a RED Policy: Output Markets

Timber market

Agricultural market

quantity of timber

quantity of agricultural production
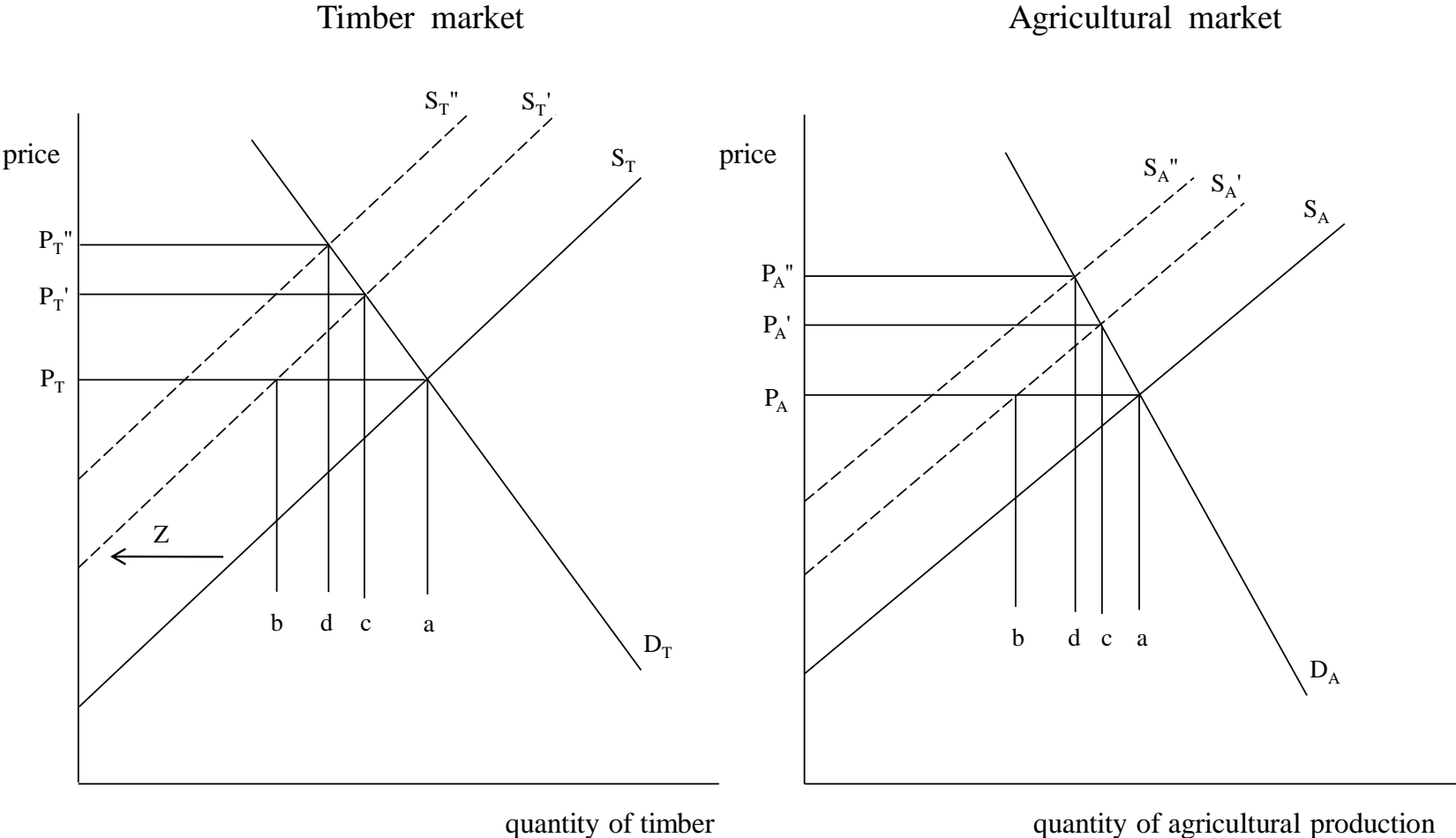
Figure 2b: Forestation Leakage with a RED Policy: Land Market

price
of
land

P_L"

P_L'

P_L

D_F "

D_F '

D_F

price
of
land

D_A "

D_A '

D_A

b   c   d   a

agricultural land
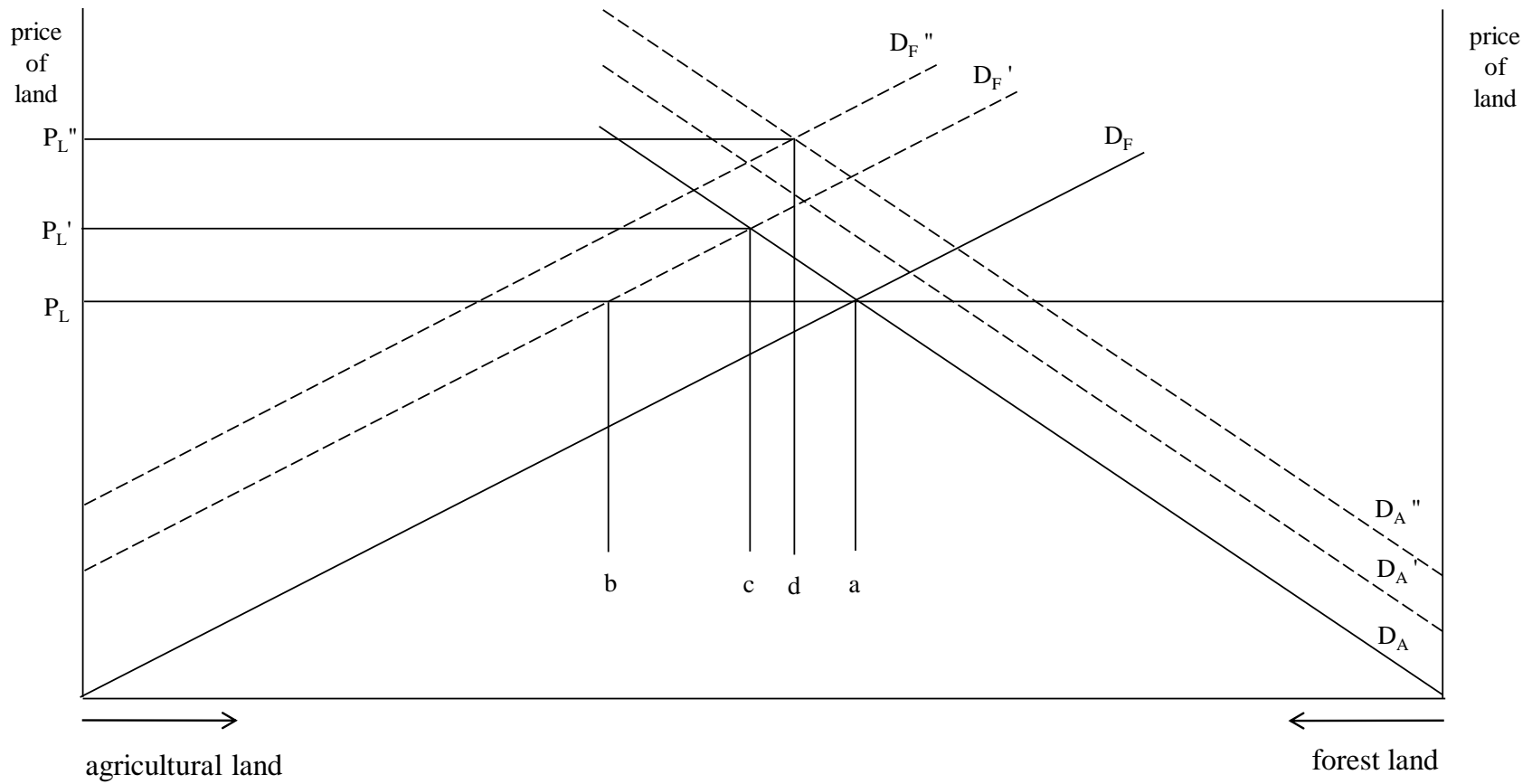
forest land

Figure 3: Avoided Emissions and Sequestration Profiles of Various RED-related Activities

1. Avoided carbon emissions due to RED

CO_2 emitted/ton of timber

Duration of the project

$S_1(t)$

T   time

- - - - - - - Cumulative emissions/sequestration

2. Carbon sequestration due to RED

CO_2 sequestered/ton of timber

T

$S_2(t)$

t_0 t_1 time

———————— Incremental emissions

3. Carbon sequestration due to afforestation

CO_2 sequestered/ton of timber

Duration of the project

$S_3(t)$

T   time

- - - - - - Cumulative emissions/sequestration

4. Carbon sequestration of afforestation on agricultural land

CO_2 sequestered/ton of timber

$S_4(t)$

T

t_0 t_1 time

———————— Incremental emissions