Carbon Leakage with Forestation Policies

Harry de Gorter
Professor
Charles H. Dyson School of Applied Economics and Management,
Cornell University, USA
hd15@cornell.edu

Dusan Drabik
Graduate student
Charles H. Dyson School of Applied Economics and Management,
Cornell University, USA
dd387@cornell.edu

David R. Just
Associate Professor
Charles H. Dyson School of Applied Economics and Management,
Cornell University, USA
drj3@cornell.edu

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24-26, 2011.

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Harry de Gorter, Dusan Drabik, and David R. Just

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RED; and (6) relative carbon sequestration potential of the forest planted on an afforested land and of the forest withdrawn from timber harvest.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

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

[1] For ease of reference, we use "carbon" to refer to all greenhouse gases emitted or sequestered as a result of a forest policy.

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.

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 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.[2] 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.[3] This translates into a contraction of the Home timber supply which is depicted as a horizontal shift from *S* to *S′*

[2] The results of the paper are independent of the country being an exporter or importer.
[3] The length of the period is typically specified in the contract of the project under the Clean Development Mechanism.

(in the first panel of Figure 1) by the reduced quantity of timber Z.[4] 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. 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:

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

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

[4] 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.

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.[5] 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

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

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 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 4). 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 up 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 model, when the land market is included, is that the RED policy, through an increase in timber prices, induces afforestation. Although market leakage of the RED policy occurs, all is not lost because the new forest sequesters carbon from the atmosphere, thus providing carbon savings associated with increased timber harvest that represents leakage associated with the RED policy.

The RED policy is usually implemented through projects with a pre-specified duration of T years. When an area of forest is withdrawn from timber harvest, the carbon savings occur as (*i.*) avoided carbon emissions from not harvesting the forest and (*ii.*) a continuation of carbon sequestration of that forest.

The rates at which harvested timber releases carbon or a standing forest sequesters it are not constant and evolve in time. The first panel of Figure 3 shows a cumulative function of carbon released when a tonne of timber is harvested (dashed line). A value of that function at any point represents an amount of carbon accumulated in the atmosphere in the process of carbon release, starting at the time of harvest. The solid line in the first panel represents an instantaneous increment of carbon released. This function is typically decreasing over time, reflecting the observation that carbon is released at the fastest rate early after the timber harvest and then the rate decays over time. The area under the incremental carbon release curve measures the amount of carbon released over some period. For a RED policy it represents avoided carbon emissions from prevented harvest.

The second panel of Figure 3 shows a similar concept as just presented; the only difference is that the dashed and solid curves represent cumulative carbon sequestration of the forest prevented from harvest and the instantaneous increment in the carbon sequestered, respectively. Those curves depict the carbon profile of an "old" forest, thus the project period starts at some time t_0 (and not at the origin, as in the first panel). The area under the incremental emissions sequestration curve between the times t_0 and t_1 denotes the total carbon sequestration of the forest withdrawn from harvest over the project period.

The total carbon savings of reduced timber production per tonne of timber are therefore:

$$E_R = \int_0^T S_1(t)dt + \int_{t_0}^{t_0+T} S_2(t)dt \tag{4}$$

and the average annual savings over the project duration are:

$$e_R = \frac{1}{T}\left(\int_0^T S_1(t)dt + \int_{t_0}^{t_0+T} S_2(t)dt\right) \tag{5}$$

where the notation is the same as in Figure 3.

Timber growing on a newly afforested land (induced by RED) sequesters carbon in two ways. First, the new forest sequesters carbon (the dashed curve in the third panel represents accumulation of sequestered carbon over time, while the solid curve depicts an instantaneous rate of sequestration). Second, there are avoided carbon emissions that would have resulted from the use of agricultural land (e.g., plowing) (fourth panel).[6] The total amount of carbon sequestered through induced afforestation is:

$$E_A = \int_0^T S_3(t)dt + \int_{t_0}^{t_0+T} S_4(t)dt \tag{6}$$

with average annual sequestration potential of

$$e_A = \frac{1}{T}\left(\int_0^T S_3(t)dt + \int_{t_0}^{t_0+T} S_4(t)dt\right) \tag{7}$$

Equations 5 and 7 show that the average annual carbon savings and sequestration potentials depend not only on the duration of a RED project, but also on the curvature of the respective curves.

The above analysis complicates quickly when the project period is extended to infinity (for the purpose of a cost-benefit analysis) and carbon prices are incorporated. Since the latter are expected to rise (see, e.g., de Gorter and Tsur 2010), the amount of carbon saved will have a different social value. Equations (4) - (7) could be modified to reflect this. It is very possible that savings from AR (although not analyzed here) are higher than from RED. The third panel of Figure 3 shows higher savings later when carbon prices are higher so one cannot unambiguously

[6] The cumulative emissions curve for agricultural land oscillates around the horizontal axis, reflecting the fact that agricultural plants are carbon-neutral by definition – the amount of carbon stored in the soil released at plowing is gradually sequestered in the next period through the process of photosynthesis. Provided that modern land-cultivating technologies, such as zero-tillage, are used, plants can even store more carbon that released during their production.

compare, for a given discount rate, because of the increasing carbon prices. The result depends 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 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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Appendix 1: Formula for Market Leakage with a RED Policy, Trade, and No Land Market

Market equilibrium with R hectares of forest – measured in the quantity of timber – set aside due to a RED policy is given by:

$$D_H(P)+D_F(P)=S_H(P)+S_F(P)-R \tag{A1.1}$$

where D denotes demand for timber, S supply of timber, P world price of timber, and the subscripts H and F denote the Home and Foreign country, respectively.

Totally differentiating (A1.1), we get:

$$dP/dR=1/\left(S_H'+S_F'-D_H'-D_F'\right)>0 \tag{A1.2}$$

A change in Home country's timber production due to R hectares of forest set-aside is

$$\frac{dS_H}{dR}=\frac{dS_H}{dP}\frac{dP}{dR}=\eta_{SH}\frac{S_H}{P}\frac{1}{\left(S_H'+S_F'-D_H'-D_F'\right)}>0 \tag{A1.3}$$

Similarly for the change in timber production in the Foreign country:

$$\frac{dS_F}{dR}=\frac{dS_F}{dP}\frac{dP}{dR}=\eta_{SF}\frac{S_F}{P}\frac{1}{\left(S_H'+S_F'-D_H'-D_F'\right)}>0 \tag{A1.4}$$

where η denotes elasticity.

Total market leakage L_M due to a RED policy is

$$L_M=\left(dS_H+dS_F\right)/R=\left(\eta_{SH}S_H+\eta_{SF}S_F\right)/\left(P\left(S_H'+S_F'-D_H'-D_F'\right)\right) \tag{A1.5}$$

After transformation of the derivatives of the demand and supply curves into their elasticity forms, we get the final formula for market leakage with a RED policy

$$L_M=\left(\phi\eta_{SH}+(1-\phi)\eta_{SF}\right)/\left(\phi\eta_{SH}+(1-\phi)\eta_{SF}-\rho\eta_{DH}-(1-\rho)\eta_{DF}\right)$$

where $\rho=D_H/\left(D_H+D_F\right)$ and $\phi=S_H/\left(S_H+S_F\right)$.

Appendix 2: The Relation between the Curvature of a Production Function and Elasticity of a Product Supply Curve

Assume a firm that uses only one input *x* to produce an output *q* through a production function $g(\cdot)$ satisfying $g(0)=0$, $g_x>0$, and $g_{xx}<0$, where the subscript denotes the derivative of the production function with respect to *x*. The firm seeks to minimize production costs

$$\min_x C = rx,\ s.t.:\ g(x)=q \tag{A2.1}$$

where *r* denotes a price per unit of input *x*.

The properties of $g(\cdot)$ guarantee that it has an inverse, h, such that $g^{-1}(q)=h(q)=x$. The cost of production can thus be written as $C=rh(q)$. The competitive firm equalizes its marginal costs with a market price, *p*, of the product

$$MC = dC/dq = rh_q = p \tag{A2.2}$$

Totally differentiating (A2-2) and rearranging, we obtain

$$dq/dp = 1/rh_{qq} \tag{A2.3}$$

By Inverse function theorem we have:

$$h_q(q) = 1/g_x(h(q)) \tag{A2.4}$$

Totally differentiating (A2-4) and rearranging yields:

$$h_{qq} = -g_{xx}/g_x^3 \tag{A2.5}$$

The supply elasticity of a product is defined as:

$$\eta_S = (dq/dp)(p/q) \tag{A2.6}$$

Combining equations (A2-2) to (A2-6), we get the sought result:

$$g_{xx} = -\frac{g_x^2}{\eta_S g(x)} \tag{A2.7}$$

Appendix 3: Formula for Market Leakage with a RED Policy under Autarky: An Interaction with the Land and Agricultural Markets

Consider a competitive market where timber and agricultural produce are produced through technologies exhibiting decreasing returns to scale: $f(\cdot)$ and $g(\cdot)$, respectively. The total area of available land *L* is fixed and is allocated between the forest L_F and the agricultural sector L_A. Although prior to the policy all forestry land is used for timber production, it, nevertheless, can be thought of as comprising of two parts: one that will be set aside in the future *R* and the other L_T that will be used for timber harvest after the policy. By setting aside *R* hectares of forest, *Z* tonnes of timber per year are effectively withdrawn from the market and the amount of timber available for harvest is given by a fraction of total timber production coming from the land used for timber production.

The model structure is as follows:

$$q_T = f(L_F) \tag{A3.1a}$$
$$q_A = g(L_A) \tag{A3.1b}$$
$$c_T = D_T(P_T) \tag{A3.1c}$$
$$c_A = D_A(P_A) \tag{A3.1d}$$
$$c_T = (L_T / L_F) q_T + Z \tag{A3.1e}$$
$$c_A = q_A \tag{A3.1f}$$
$$f_L P_T = P_L \tag{A3.1g}$$
$$g_L P_A = P_L \tag{A3.1h}$$
$$L_T + R = L_F \tag{A3.1i}$$
$$L_F + L_A = \overline{L} \tag{A3.1j}$$

Equations *a* and *b* describe production and *c* and *d* consumption of timber and agricultural products, respectively. Equations *e* and *f* constitute equilibrium conditions in the timber and agricultural market, respectively. First-order conditions *g* and *h* determine demand for forest and agricultural land, respectively. Land rent is assumed to equalize in the equilibrium. Finally, equations *i* and *j* are land accounting identities. The former says that a part of total forest land will be allocated to timber production and the rest will be set aside, whereas the latter means that the total available land is allocated to forestry and agriculture.

Production and consumption is denoted by q and c, respectively, with subscripts T, A, F, and L standing for timber, agriculture, forest, and land respectively. Capital letters P and L denote price in the input and output markets and an area of land, respectively. The timber equivalent of the land set aside, Z, due to the RED policy is computed in the initial equilibrium as $Z = \left(R/L_F\right)q_T$ and thus is exogenous.

Totally differentiating the system (A3.1) yields:

$$\begin{aligned}
&dq_T = f_L dL_F \\
&dq_A = g_L dL_A \\
&dc_T = D_T' dP_T \\
&dc_A = D_A' dP_A \\
&dc_T = \frac{q_T}{L_F} dL_T + \frac{L_T}{L_F} dq_T - \frac{L_T q_T}{L_F{}^2} dL_F + dZ \\
&dq_A = dc_A \\
&f_{LL} P_T dL_F + f_L dP_T = dP_L \\
&g_{LL} P_A dL_A + g_L dP_A = dP_L \\
&dL_T = dL_F \\
&dL_F + dL_A = 0
\end{aligned} \tag{A3.2}$$

Market leakage of a RED policy is defined as a change in the timber harvest resulting from a withdrawal of Z tonnes of timber from the market because of the policy. Mathematically, it is defined as:

$$L_M^T \approx -dq_T / dZ \tag{A3.3}$$

where $dZ \approx 0 - Z = -Z < 0$ denotes a reduction in available timber due to the RED policy. In order to get a meaningful positive value of a market leakage, we place a negative sign in equation (A3.3).

Solving the system (A3-2) for the derivative in (A3-3), we obtain:

$$L_M^T \approx \frac{\dfrac{f_L}{D_T{}'}}{\dfrac{f_{LL}}{f_L}P_T + \dfrac{g_{LL}}{f_L}P_A + \dfrac{g_L{}^2}{f_L D_A{}'} + \dfrac{1}{D_T{}'}\dfrac{q_T}{L_F}\left(1-\dfrac{L_T}{L_F}\right) + \dfrac{f_L}{D_T{}'}\dfrac{L_T}{L_F}}$$

Using the result from Appendix 2, equations from (A3-2), and after transformation of the derivatives into their elasticity form, we arrive at:

$$L_M^T \approx \frac{\dfrac{\alpha}{\eta_{DT}}}{\alpha\left(\dfrac{\gamma}{\eta_{DT}} - \dfrac{1}{\eta_{ST}}\right) + \beta\left(\dfrac{1}{\eta_{DA}} - \dfrac{1}{\eta_{SA}}\right) + \dfrac{\gamma(1-\gamma)}{\eta_{DT}}} \tag{A3.4}$$

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.

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

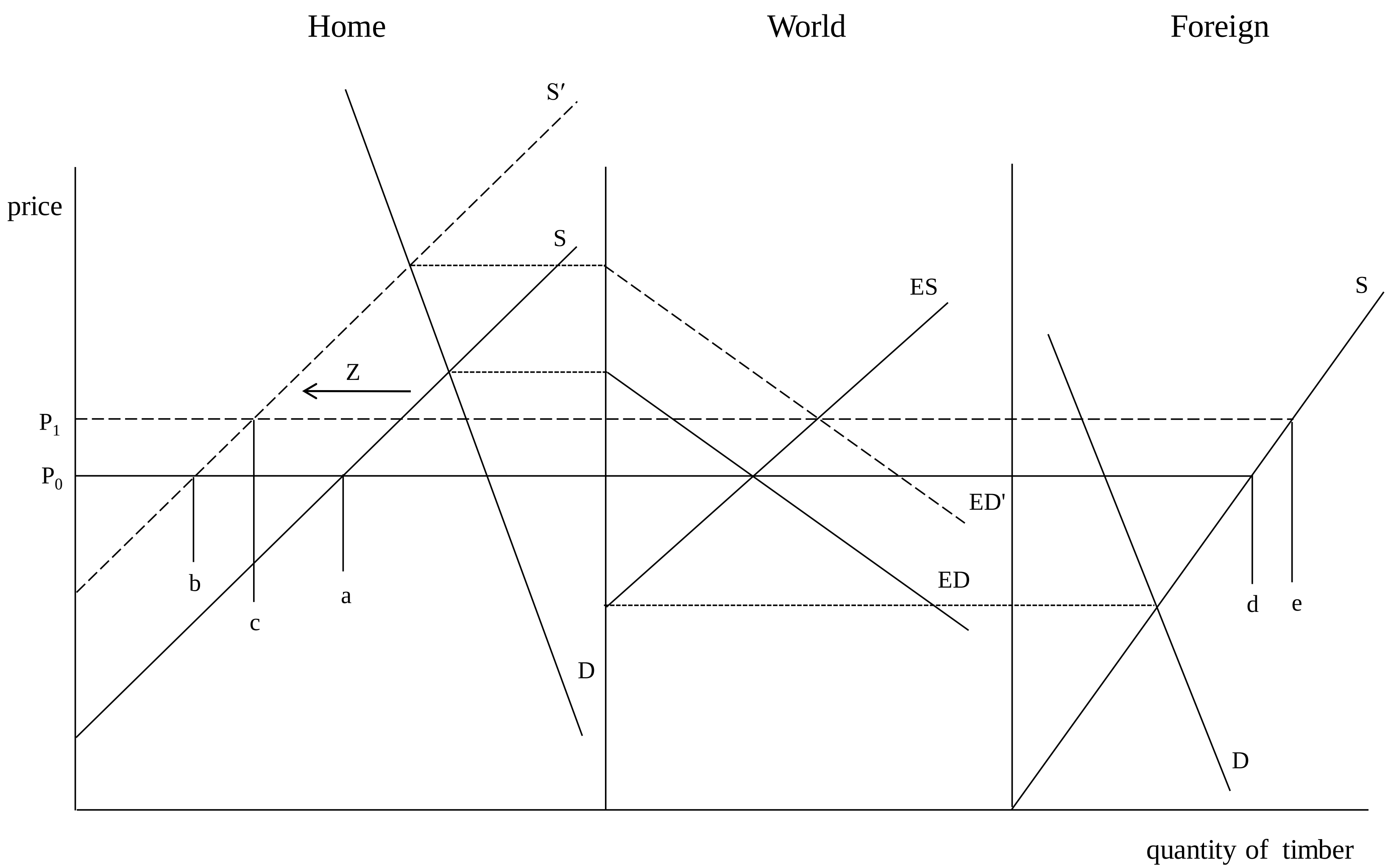

Figure 2a: Forestation Leakage with a RED Policy: Output Markets

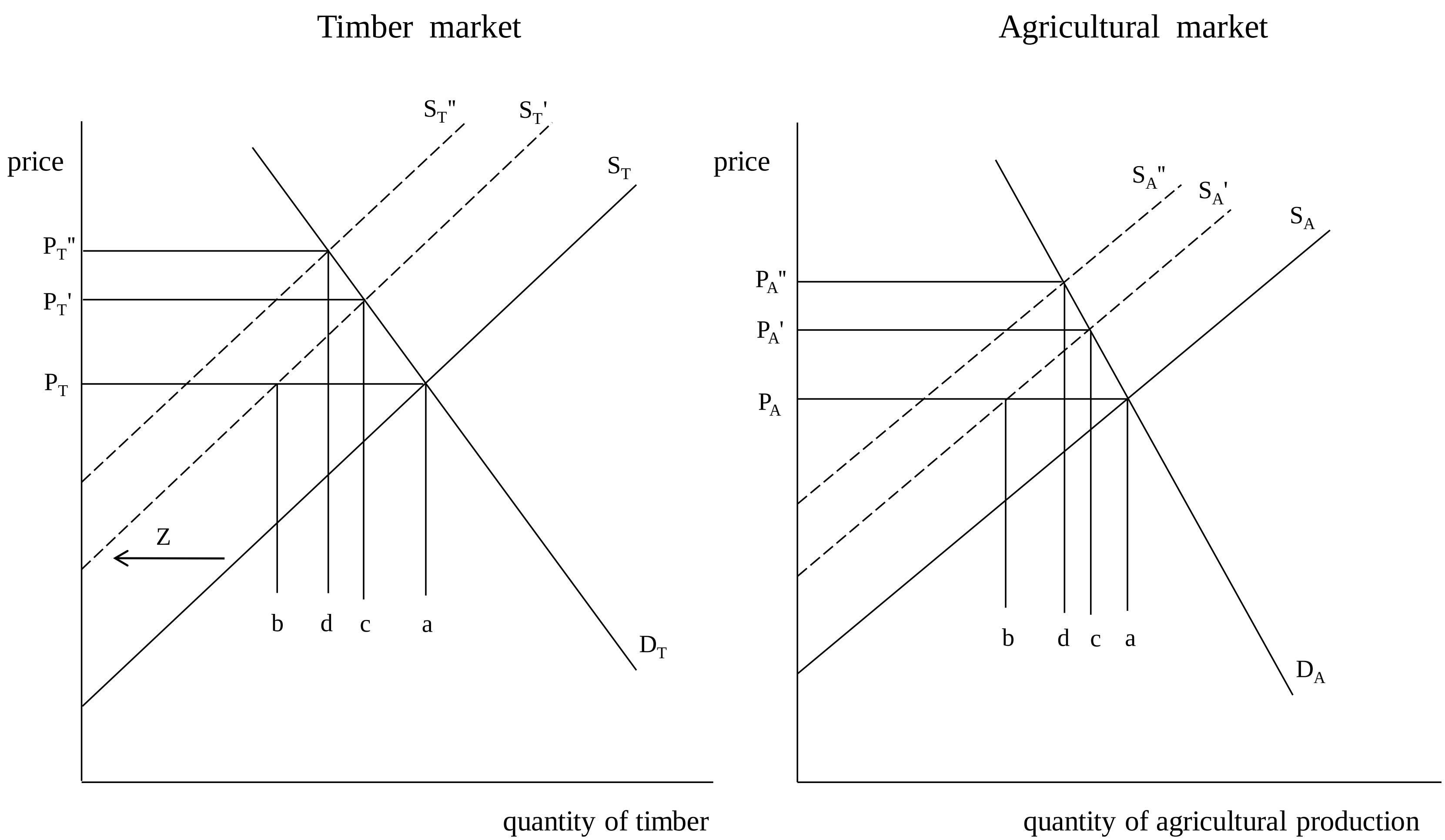

Figure 2b: Forestation Leakage with a RED Policy: Land Market

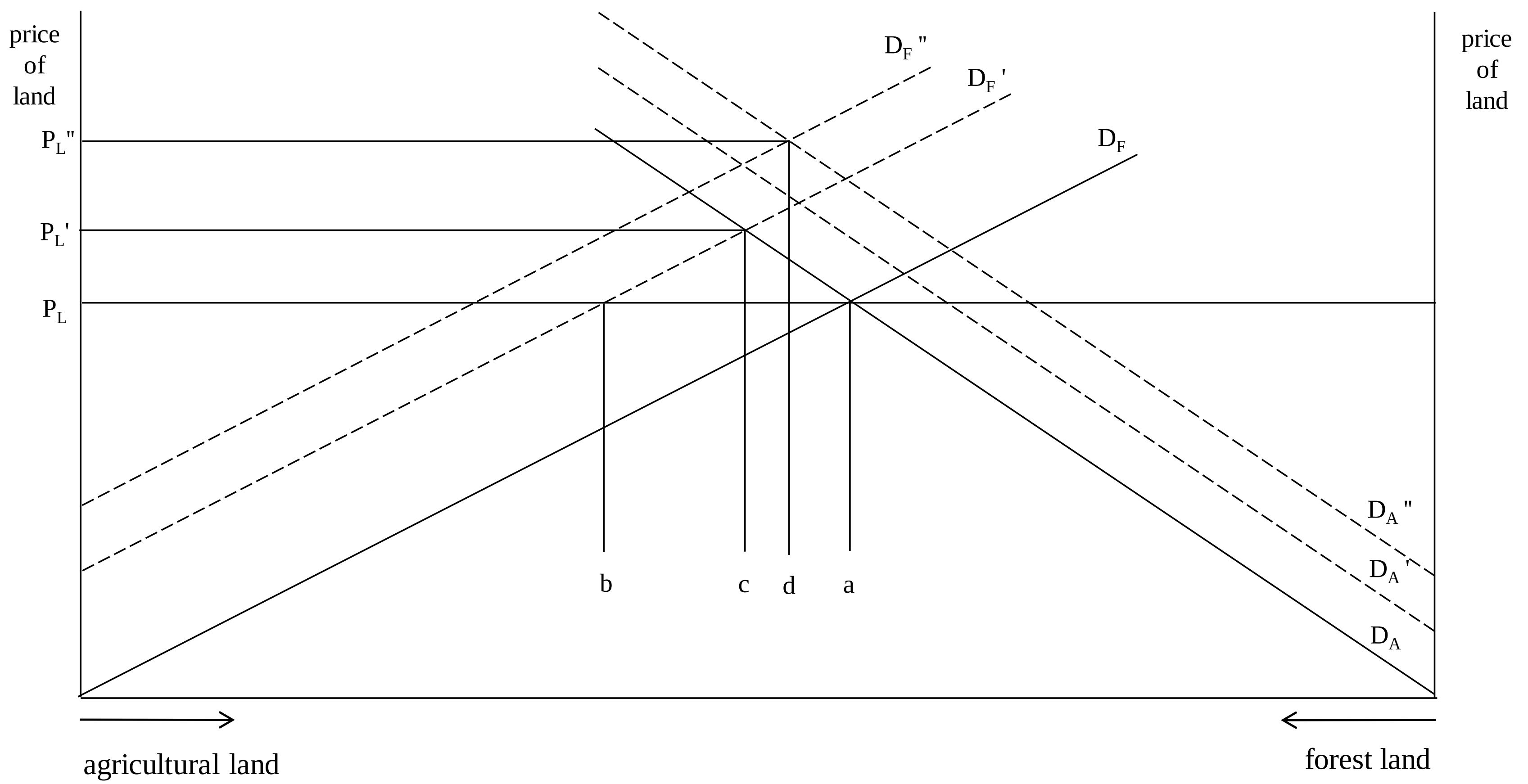

Figure 3: Avoided Emissions and Sequestration Profiles of Various RED-related Activities