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# Conservation of forest through provision of alternative sources of income; evidence from rural households in Northern Pakistan

*Muhammad Tufail*[1], *Ather Maqsood Ahmed*[1], *Shahzad Alvi*[2]*

[1]*National University of Sciences and Technology, Islamabad, Pakistan*

[2]*Pakhtunkhwa Economic Policy Research Institute, Abdul Wali Khan University, Mardan, Pakistan*

**Corresponding author: shahzad.alvi@s3h.nust.edu.pk*

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**Abstract:** The collection of forest products by indigenous communities is the main cause of deforestation and a major obstacle to efficient forest management. This study develops a time allocation model for a representative household living in the peripheries of the forest. It is assumed that the household allocates their labour time between three activities: agriculture, forest product extraction, and off-farm activities. Households maximize their net income subject to the available forest resources. Using the Optimal Control Theory and applying the unique and global maxima, the results of the comparative static and dynamic analyses suggest that higher agricultural efficiency, agricultural output prices, and higher off-farm wages maximize the forest stock. Besides that, knowledge of forest extraction and farming may also yield the higher equilibrium of forest stock while higher forest and input prices encourage forest resource extraction. The result from the tobit analyses of a socio-economic survey from the Malakand Division forest in Pakistan provides supportive empirical evidence.

**Keywords**: forest degradation; agricultural inefficiency; theoretical model; static and dynamic analysis; deforestation; Pakistan

The benefits of forest can be seen from its contribution to the public wealth and as a source of livelihood to forest-dependent communities. Forests provide environmental sustainability in the form of carbon storage, habitat to several species, biodiversity and storm mitigation. Notwithstanding these benefits, forests are degraded at an alarming rate due to economic marginalization (Araujo et al. 2010; Barber et al. 2014). Forest covers are depleted over time through overexploitation and conversion of forest land to cropland, settlement, pasture and urban expansion (Rudel et al. 2009; Hansen et al. 2013). In view of the changing global environment, the preservation of these forests is crucial for several, yet diversified reasons. On the one hand, more than 75% of the world's biological diversity living in these forests, which is irreplaceable, is disappearing at an alarming rate (Oates 2002). More than one billion people are living in the peripheries of these forests who are primarily dependent on forest products for their livelihood (Guppy 1984; FAO 2007). On the other hand deforestation is, therefore, an existential threat to them.

In response to the problem of deforestation regionally, the governments in the developing countries reacted through several policy instruments such as assigning the status of protected forest (e.g. wildlife reserves, heritage sites, and national parks, etc.) and enacted through regulations to restrain the use of forest resources. These efforts have resulted in almost 8 500 distinct protected areas that cover over 800 million ha of land, and they mostly exist in the developing countries (WRI 1994). On the other hand, these protectionist policy measures

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provide global public goods in the form of eco-tourism, biodiversity, and environmental sustainability.

The drivers of deforestation are diverse; economists have long argued that agricultural activities are the main cause of deforestation as well as the public policy that encourages farming and accelerates deforestation. The agents of deforestation are influenced by many factors, such as the biophysical characteristics of the forest land, slope, elevation, and the suitability of the soil for farming and return to cleared land. The demand for agricultural goods, timber products, and expected revenue from forest product collection is magnified by forest product prices. Household decision to convert forest land into agriculture is driven by the prices of agricultural goods, forest products and the next best use of cleared land. All these decisions mostly made in the context of governance regimes consist of multiple property rights (protected public lands, open access land, leased concessions, and private ownership) (Geist, Lambin 2002; Chowdhury 2006).

Whereas Ehui et al. (1990) showed that higher returns to farming stimulate deforestation and forest degradation, Deacon's (1995) general equilibrium analysis suggested that public policies could be instrumental in reducing deforestation through the reduction of profitability from agricultural production. Both studies have assumed that farming is an increasing function of deforestation. Particularly, the assumption of agricultural activities as a direct function of deforestation may not hold in the case of already protected forests in which forest-agriculture boundaries are well defined, forest zones are demarcated between surrounding areas and expansion of agriculture in forest areas is prohibited by the legislation. In the case of protected forest, agricultural rent is a decreasing function of distance from the market, rent tends to decline as the distance increases and the change does not likely occur either in rent or in forest cover (Hyde, Kohlin 1999). The cost of establishing property rights determines the extent of encroachment and deforestation, thus the cost increases as the forest land is declared as protected land. So, at some point the cost of extracting forest increases high enough that agricultural expansion on forest land becomes uneconomical (Sedjo, Lyon 1990; Vincent, Gillis 1998). These studies further suggest that in most of the developing countries where the forest was declared as protected forest protection becomes a norm and forest cover may continue to decrease shortly.

The depletion of natural resources in Pakistan is alarming (Ahmad et al. 2012; FAO 2015). While the extent of deforestation is still the main issue among policymakers, to reverse the process of deforestation, the government of Pakistan imposed a ban on timber extraction in 1992 (Suleri 2002). The total forest area in Pakistan is about 5% of the total land area (881 293 km$^2$). Out of the total forest area, the natural forest accounts for 55% and is under pressure of timber extraction for construction and infrastructure (Bukhari et al. 2012). Pakistan ranks 113$^{th}$ in the world based on forest per capita (0.03 ha per capita forest) and is continually in decline due to population growth (NIPS 2009). The first Forestry Sector Master Plan (FSMP) of Pakistan was conducted in 1992, based on remote sensing to assess the nature of forest cover, deforestation and forest degradation. The study has confirmed that Pakistan is losing the forest cover of 27 000 ha annually at the rate of 0.7%. As the FSMP has a serious methodological limitation, the extent of deforestation was found questionable. Another study by FAO (2010) reported that the forest cover loss in Pakistan for 1990, 2000, and 2010 was 2.5, 2.1 and 1.7 million ha, respectively, at a rate of 1.6% and 2.0% for the period 1990–2000 and 2000–2010.

All of the above studies are based on satellite mapping and remote sensing and they only deal with the land use and land cover changes and rates of deforestation. The goals of these studies are to understand the extent of deforestation and forest degradation. Hence, the current literature is lacking the theoretical foundation of understanding the deforestation phenomenon. In this study, an attempt is made to find out the possible theoretical relationship between the drivers of deforestation and the nature of the factors of deforestation that can affect forest cover. We have developed a theoretical model for forest product collection by the households living in the peripheries of protected forest. Both comparative static and dynamic analyses are performed to capture the effect of exogenous variables on the equilibrium value of forest resources. The dynamic analysis suggests that increasing agricultural efficiency, higher agricultural prices and lower agriculture input prices, and off-farm wages increase the equilibrium stock of forest resources.

The paper is organized in the way that section two deals with the development of the household time allocation model in forest product collection and the associated conditions of optimality. The com-

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parative static and dynamic analysis of the model is discussed at the end of section two. Section three consists of an empirical analysis of the household model findings while section four concludes the paper.

## THEORETICAL MODEL

To understand how the anthropogenic and policy factors influence forest product extraction, it is important to develop a conceptual relationship between farming activities and forest product extraction. Some studies have attempted to observe the fundamentals of deforestation (Godoy et al. 1993; Amacher et al. 1999; Caviglia, Harris 2004). These studies deal with household characteristics that lead to deforestation. A limited number of studies e.g. by Shively (2001), Kissinger (2012) and Meyfroidt et al. (2013) have incorporated the economic variables along with the variables for the agriculture sector, including the labour wages, the price of agricultural products, and other income sources. With the absence of a theoretical framework, sometimes the empirical studies lead to some erroneous policy consequences. Firstly, one cannot understand the channel of causation how the independent variable affects the dependent variable. Secondly with the absence of a theoretical framework, one cannot even accurately formulate the empirical model. So, to understand how an agent's behaviour can influence natural resource conservation, we have developed a theoretical model based on household behaviour.

The community living in the peripheries of forest is acting as a self-optimizing agent, involved in the extraction of forest resources for multiple purposes such as safety nets, consumption smoothing, and getting away from the poverty trap. As for the safety net, the household extracts forest resources for any shortfall in income. We conjecture that the motive behind the collection of forest resources allows the household to maintain the current level of consumption. This strategy prevents the household from falling into deeper poverty. The last coping strategy is to get away from the poverty trap as the extracted forest resources provide the household the opportunity of "stepping out" and "stepping up" strategies. The extracted forest product used for income accumulation leads to capital accumulation that subsequently leads to moving to other activities, stepping out strategy or getting specialization in the existing activities that lead to an intensification of forest resources extraction (Dorward, Anderson 2002).

The model deals with rural household income generation strategies in the forest area. Due to the lack of industrial sector development and underdeveloped informal sector, most of the rural households are primarily dependent on agriculture for basic livelihood. It is, therefore, important to link up agricultural activities and household income generation strategies. Most of the area in Malakand division (one of the largest divisions of the province Khyber Pakhtunkhwa, Pakistan, which consists of seven districts with a population of almost 7.5 million; GOP Census 2017) consists of agricultural land. About 84% of the population in the area is primarily dependent on agriculture (Agriculture Statistics GOP 2014). In the context of agricultural dependency, it is important to highlight the role of technical efficiency in the agricultural sector. Any inefficiency in the agriculture sector drives the rural household to look for additional means of earning to maintain consumption smoothing.

To understand how the technical efficiency of the agriculture sector alters forest dependency, we need to develop a theoretical relationship between forest product extraction and agricultural efficiency. Following Angelsen (1995), Gunatilake and Chakravorty (2000) and Shively (2001), we have developed a time allocation model for the representative household living in the peripheries of the forest. Using the labour time allocation model, it is assumed that a representative household is involved in three types of income generation activities, namely agriculture, forest extraction, and off-farm work. Activities in the agriculture sector are represented by a subscript (a), forest-based activities are represented by (f), and off-farm activities are represented by (o). Households also receive social security (income support) from both the provincial and federal governments. It is assumed that the households collect forest products, which are marketable. Here we assume that the forest product collected by household is a single type or all the forest products are aggregated in a single good. While forest products are diverse consisting of both timber and non-timber, where timber is for commercial use and fuelwood, the non-timber uses include fruits, fodder, oils and vegetables, medicinal plants, etc.

The function of household agricultural production is given by

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$$Y_a = \phi\,(L_a, I_a, A_a\!: Z_p, E_a) \quad (1)$$

where:
$Y_a$ – household agricultural production;
$L_a$ – household labour allocated to agriculture;
$I_a$ – purchased agricultural inputs;
$A_a$ – area under cultivation;
$Z_p$ – household characteristics;
$E_a$ – technical efficiency in agriculture.

$$Y_{L_a} > 0,\ Y_{L_{aLa}} < 0,$$
$$Y_{I_a} > 0,\ Y_{I_{aIa}} < 0,$$
$$Y_{A_a} > 0,\ Y_{A_{aAa}} < 0,$$
$$Y_{I_{aAa}} > 0,\ Y_{L_{aAa}} > 0,\ Y_{L_{aIa}} > 0$$

The above partial derivatives indicate that agricultural production is increasing the function of inputs but at a diminishing rate. The choice variable is labour time to forest allocation and the amount of inputs used in agricultural production.

The forest collection function is given by the labour time used in forest product extraction, characteristics of the representative household such as the age of household head, family size, education and health of the household head, and distance from market and forest, knowledge of forest product extraction (experience). The forest collection function is given by

$$Y_f = \psi\,(L_f, Z_p, K_f, F) \quad (2)$$

where:
$L_f$ – household labour time in forest collection;
$F$ – quality and access to the forest;
$K_f$ – knowledge of forest product extraction.

Similar to agricultural production the forest collection function is also assumed to be concave. Labour supply in the extraction of forest products is a part of total labour supply and can be determined through time used in other activities such as labour supply in the agriculture and non-agriculture sector. The net income of the representative household is the sum of all incomes received from agriculture, forest extraction, from off-farm activities, and social security programs. Symbolically, the net income is given by

$$NI_i = P_a\,[\phi\,(L_a, I_a, Z_p, A_a\, E_a)] - P_I I_a + + P_f\,[\psi\,(L_f, K_f, Z_p, F)] + W(L_0) + IN(S_c) \quad (3)$$

where:
$NI$ – total net income, i.e. income generated through agriculture, forest and off-farm labour market activities plus transfer payments received from the government minus the cost of inputs;
$P_a$ – price of agricultural goods;
$P_I$ – price of agricultural inputs;
$P_f$ – forest product prices;
$W$ – wages in off-farm activities;
$IN$ – benefits received from social safety net programs.

The labour time is divided between agriculture, forest collection, off-farm activities, and leisure.

$$\bar{L} = L_a + L_f + L_o + L_l \quad (4)$$

The household maximizes its utility based on net income and leisure time predetermined at the beginning of each crop season.

We define the forest growth function without harvesting as

$$\dot{X} = f(x_t, \gamma, k) \quad (5)$$

where:
$x_t > 0$ – stands for the current stock of the forest;
$\gamma$ – intrinsic growth;
$k$ – forest carrying capacity.

Forest extraction function $h_t$ can be represented as:

$$h_t = h(x_t, L_f) \quad (6)$$

Then the net forest growth function will be represented by

$$N\dot{X} = F(x_t, \gamma, k) - h(x_t, L_f) \quad (7)$$

The forest harvesting function is increasing in both labour time to forest extraction and resource stock.

Assuming $NI = C$ $C$ = total household consumption.

The representative household intertemporal utility function is given by

$$\max_{l_f I_a} \int_0^{\infty} U(NI)\, e^{-\rho t} dt \quad (8)$$

Subject to constraint $N\dot{X} = F(x_t, \gamma, k) - h(x_t, L_f)$

where:
$\rho$ – discount rate
$U$ – satisfies the condition of $U' > 0$, $U'' < 0$ depends on the household's net income ($NI$).

Now putting the equation of net income to set the current value of the Hamiltonian function, the current value of the Hamiltonian function is given by

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$$H_c = U([P_a \, \varphi \, (L_a, I_a, Z_p, A_a \, E_a)] - P_i I_a] + \\ + P_f \, \psi \, (L_f, K_f, Z_p, F) + W(L_0) + IN(S_c) + \\ + \lambda[F(x_t, \gamma, k) - h(x_t, L_f)] \quad (9)$$

where:

λ – co-state variable in the Hamiltonian function along with other exogenous parameters such as $P_a$, $P_f$, $P_i$, λ, $W$, $K$ and ρ.

The first-order conditions with respect to $I_a$, $L_f$, $l_a$, and $L_o$ are:

$$\frac{\partial H_c}{\partial I_a} = u_i^{'} = P_a Y_{ai} - P_i = 0 \quad (10)$$

$$\frac{\partial H_c}{\partial L_f} = u_{l_f}^{'} = -P_a Y_{aL_a} + P_f Y_{fl_f} - \lambda h_{l_f} - W = 0 \quad (11)$$

$$\frac{\partial H_c}{\partial L_a} = u_{l_a}^{'} = P_a Y_{aL_a} - P_f Y_{fl_f} + \lambda h_{l_f} - W = 0 \quad (12)$$

$$\frac{\partial H_c}{\partial L_o} = u_{l_o}^{'} = -P_a Y_{aL_a} - P_f Y_{fl_f} + \lambda h_{l_f} - W = 0 \quad (13)$$

The time path of the state variable can be written as:

$$-\frac{\partial H_c}{\partial \lambda} = N\dot{X} = F\left(x_t, \gamma, k\right) - h\left(x_t, L_f\right) \quad (14)$$

The time path of the co-state variable

$$-\dot{\lambda} = -\rho\lambda + \left[P_f h_{x_t} + \lambda\left(F_{x_t} - h_{x_t}\right)\right]$$
$$\dot{\lambda} = \rho\lambda - \left[P_f h_{x_t} + \lambda\left(F_{x_t} - h_{x_t}\right)\right] \quad (15)$$

Equation (10) represents the equality of marginal benefit and marginal cost obtained from an extra unit of input used in agriculture. The marginal benefit is the incremental increase in agricultural production from one unit increase in input while the marginal cost incurred from the purchase of one unit of input is the price of an input used in agriculture. Equation (11) represents the equality of marginal products of forest collection to its marginal cost. The marginal product of labour time spent in forest collection is represented by $P_f Y_{f l_f}$ while the marginal cost of labor time is labor supply not employed in agriculture plus off-farm wage activities and the forest resources extracted today which will not be available tomorrow.

Accordingly, if $P_f Y_{f L_f} - h_{L_f} = P_a Y_{a L_a} + W_{L_o} > 0$, it means that forest product prices are higher than the shadow price of forest stock. While Equation (14) represents the net growth in forest stock,

rearranging Equation (15) we get:

$$\rho\lambda - \dot{\lambda} + \lambda h_x = P_f h_x + \lambda F_x \quad (16)$$

Equation (16) shows the benefit and cost of forest resources extraction. The benefit is represented by $P_f h_x$ and indirect benefit from the natural growth of forest by $\lambda F_x$.

For obtaining the dynamic solution of the model the following identities will be used.

$$I_a = \hat{I}_a(\lambda, \delta),\ L_f = \hat{L}_f(\lambda, \delta),\ L_a = \hat{L}_a(\lambda, \delta),\ L_o = \hat{L}_o(\lambda, \delta)$$

where δ includes all the exogenous parameters δ = ($P_a$, $P_i$, $E_a$, $A_a$, $P_f$, $W$, $IN_s$).

## Analysis of phase diagram

Following Gunatilake and Chakravorty (2003) and Caputo (1992), the perturbed phase diagram was used to produce comparative dynamic analysis. As we are more concerned about the labour supply in forest product extraction, the detail analysis is done only for $L_f$. Putting the identities $L_f = \hat{L}_f$ (λ, δ) and $I_a = \hat{I}_a$ (λ, δ) and in the following equations:

$$\dot{X} = F\left(x_t, \gamma, k\right) - h\left(x_t, \hat{L}_f\left(\lambda, \delta\right)\right) \quad (17)$$

$$\dot{\lambda} = \rho\lambda - \left[P_f h_{x_t}\left(x_t, \hat{L}_f\left(\lambda, \delta\right)\right) + \lambda\left(F_{x_t}\left(x, \gamma, K\right) - \right.\right.$$
$$\left.\left. - h_{x_t}\left(x_t, \hat{L}_f\left(\lambda, \delta\right)\right)\right)\right] \quad (18)$$

$$x(0) = x_0 \quad (19)$$

$$\lambda(T) \geq 0,\ x(T) \geq 0,\ \lambda(T)x(T) = 0 \quad (20)$$

Putting $x(t, \beta)$, and $\lambda(t, \beta)$ in the above equation, we get the following equations.

Where β = ($P_a$, $P_i$, $E_a$, $A_a$, $P_f$, $W$, $IN_s$, γ, $K$) represent the vector of exogenous parameters.

$$n\dot{x}\left(t, \beta\right) = F\left(x\left(t, \beta\right), \gamma, k\right) - h\left(x\left(t, \beta\right), \hat{L}_f\left(\lambda, \delta\right)\right) \quad (21)$$

$$\dot{\lambda}\left(t, \beta\right) = \rho\lambda\left(t, \beta\right) - \left[P_f h_{x_t}\left(x\left(t, \beta\right), \hat{L}_f\left(\lambda, \delta\right)\right) + \lambda\left(t, \beta\right)\right.$$
$$\left.\left(F_{x_t}\left(x\left(t, \beta\right), \gamma, K\right) - h_{x_t}\left(x\left(t, \beta\right), \hat{L}_f\left(\lambda, \delta\right)\right)\right)\right] \quad (22)$$

$$x(0, \beta) = x_0 \quad (23)$$

$$\lambda(T, \beta) \geq 0,\ x(T, \beta) \geq 0,\ \lambda(T, \beta)x(T, \beta) = 0 \quad (24)$$

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The differential equation can be derived from the above equations by differentiating through a system of the ordinary differential equations. Using the boundary conditions for Equation (23) and (24);

(*i*) $\lambda(T, \beta) > 0 \Rightarrow x(T, \beta) = 0$

(*ii*) $x(T, \beta) > 0 \Rightarrow \lambda(T, \beta) = 0$

The first boundary condition shows that rural households harvest the forest products which are depleted within the planned period. While the second condition shows that at the terminal period there will be some stock of forest let over at which the shadow price of the forest will be zero.

We use the phase diagram analysis to derive the comparative dynamic results for changes in agricultural efficiency, inputs used in agriculture, and so on for the other exogenous variables.

*Agricultural efficiency.* Differentiating Equations (21)–(24) with respect to agricultural technical efficiency, we get the following system of equations.

$$\dot{\lambda}_{E_a} = \alpha_{11}\left(t,\beta^0\right)\lambda_{E_a} + \alpha_{12}\left(t,\beta^0\right)x_{E_a} \quad (25)$$

$$\dot{x}_{E_a} = \alpha_{21}\left(t,\beta^0\right)\lambda_{E_a} + \alpha_{22}\left(t,\beta^0\right)X_{E_a} - h_{L_f}\left(t,\beta^0\right)\frac{d\hat{L}_f}{dE_a}\left(t,\beta^0\right) \quad (26)$$

$$x_{E_a}\left(0\right) = 0 \quad (27)$$

$$x_{E_a}\left(T^0\right) = 0 \quad (28)$$

Proposition 1

(a) $x_{E_a}\left(t,\beta^0\right) \geq 0 \, \forall t \in \left(0,T^0\right)$

(b) $\lambda_{E_a}\left(t,\beta^0\right) \leq 0 \, \forall t \in \left(0,T^0\right)$

The proposition shows that an increase in agricultural efficiency leads to a higher equilibrium of forest stock and lower shadow price of the forest.

To determine the direction and path of the steady-state condition, let $\dot{\lambda}_{Ea} = 0$, $\dot{x}_{Ea} = 0$, and solving Equation (25) and (26) we get

$$\frac{\partial \lambda_{E_a}}{\partial x_{E_a}} = -\frac{\alpha_{12}\left(t,\beta^0\right)}{\alpha_{11}\left(t,\beta^0\right)} < 0 \quad (29)$$

$$\frac{\partial x_{E_a}}{\partial \lambda_{E_a}} = -\frac{\alpha_{21}\left(t,\beta^0\right)}{\alpha_{22}\left(t,\beta^0\right)} > 0 \quad (30)$$

The phase diagram of agricultural efficiency and an increase in efficiency derived from the system of Equations (25)–(28) show that an increase in agricultural efficiency leads to a higher level of forest resources in the entire optimum path and lower shadow price (Figure 1). An increase in efficiency leads to more profitable agriculture, which further increases labour allocation to agriculture and reduces labour supply in forest product extraction. Due to this phenomenon, the equilibrium level of forest stock increases at ceteris paribus conditions. A higher stock of forest at the equilibrium level leads to lower shadow prices. A comparative dynamic analysis for all other exogenous variables is given in the Electronic Supplementary Material 1 (ESM 1) and ESM 2.

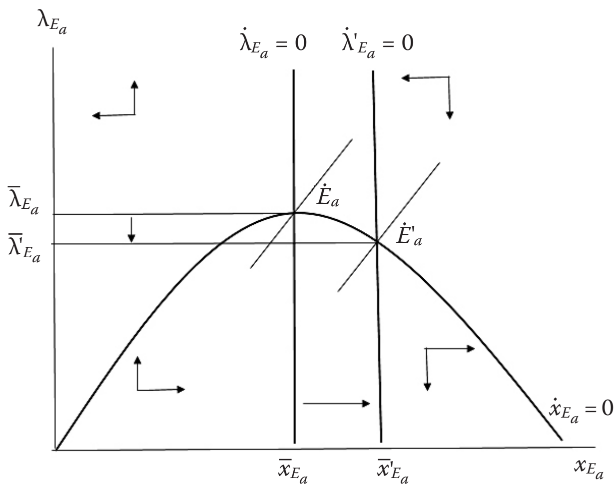


Figure 1. Phase diagram of agricultural efficiency

**Comparative analysis**

Here we follow the method outlined by Gunatilake and Chakravorty (2003) to obtain a comparative analysis. For comparative analysis, we use both the necessary conditions (10) and (11) to solve it globally and uniquely utilizing the method of Gale and Nikaido (1965) using $L_f = \hat{L}_f(\lambda, \delta)$ and $I_a = \hat{I}_a(\lambda, \delta)$ and Equations (10) and (11) will be used globally and uniquely where δ includes all the exogenous parameters $\delta = (P_a, P_i, E_a, A_a, P_f, W, IN_s)$.

Details of solving Equations (10) and (11) are given in ESM 1 and the following comparative dynamic solutions were obtained.

*Comparative dynamic analysis for labour supply in forest extraction.* The above result (Equation (31)) indicates that when the price of forest products increases, it encourages labour time to extract the forest goods because a return to labour time in for-

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est goods extraction increased vice versa for labour time in agriculture. When agricultural input price increases, the cost of agricultural activities (production) also increases. This will lead to less profitable farming and agricultural labour supply will decrease. The household readjusts their labour time from agriculture to forest extraction. An increase in the agricultural product price will lead to an increase in labour supply in the agriculture sector; due to the higher price of agricultural products the households increase labour supply in agricultural activities. Hence, higher agricultural prices lead to reduce labour supply in forest collection activities and vice versa.

Forest labour supply also decreases with an increase in off-farm wages. Results in Equation (34) (ESM 1) indicate that an increase in non-agricultural wages makes the households in the forest peripheries reallocate their labour time from forest extraction to off-farm activities. So, an increase in off-farm wages creates a trade-off between forest collection and working in the wage sector. The higher opportunity cost of working in the forest will induce households to reduce or shift their labour time from forest to off-farm activities. The impact of the government income support program also shows that any action of the government that increases household income will lead to decrease labour time given to forest product extraction indicated by Equation (35) .

Agricultural efficiency has a decreasing effect on forest labour supply. The equation above (Equation (36)) implies that when agricultural efficiency increases, less labour will be allocated to forest collection. Agricultural efficiency raises the productivity of labour in farming and increases the opportunity cost of labour supply in forest product collection. Therefore, labour supply in forest collection activities declines while an increase in the agricultural area for cultivation also decreases labour supply in forest extraction. Because agriculture in the peripheries of the forest is labour-intensive, it creates a labour shift from forest extraction to agricultural activities when the area under agricultural production increases.

Equation (38) in ESM 1 shows that the rural community is valuing the forest resources, which is an indication of the lower forest stock or the community takes the depletion of forest seriously. This means that when a representative household values the forest resources (higher shadow prices), it increases the opportunity cost of forest collection; hence a representative household will decrease their labour supply for forest product gathering.

Comparative analysis for inputs used in agricultural activities

Equation (39) shows that when forest product prices increase, it reduces the quantity of inputs used in agriculture; for example, a producer of two goods (A and B) if the price of B increases, the producer speculates that producing goods B is a lucrative business for him, so he will increase the production of B and reduce the production of A.

$$\frac{dL_f}{dP_f} = \frac{P_a Y_{aI_aI_a} Y_{fL_f}}{(P_a)^2 \left\{ Y_{aL_a} Y_{aI_aI_a} - \left( Y_{aI_aL_a} \right)^2 \right\} + P_a Y_{aI_aI_a} \left\{ P_f Y_{fL_fL_f} - \lambda h_{L_{fL_f}} \right\}} > 0 \quad (31)$$

$$\frac{dL_f}{dE_a} = \frac{-(P_a)^2 \left( Y_{aI_aI_a}.Y_{aL_aE} \right) + (P_a)^2 \left( Y_{aL_aI_a}.Y_{aI_aE} \right)}{(P_a)^2 \left\{ Y_{aL_a} Y_{aI_aI_a} - \left( Y_{aI_aL_a} \right)^2 \right\} + P_a Y_{aI_aI_a} \left\{ P_f Y_{fL_fL_f} - \lambda h_{L_{fL_f}} \right\}} < 0 \quad (36)$$

$$\frac{dI_a}{dP_f} = \frac{-P_a Y_{aI_aL_a} Y_{fL_f}}{(P_a)^2 \left\{ Y_{aL_a} Y_{aI_aI_a} - \left( Y_{aI_aL_a} \right)^2 \right\} + P_a Y_{aI_aI_a} \left\{ P_f Y_{fL_fL_f} - \lambda h_{L_{fL_f}} \right\}} < 0 \quad (39)$$

$$\frac{dI_a}{dE_a} = \frac{P_a Y_{aI_aE} \left( P_a Y_{aL_a} + P_f Y_{fL_fL_f} - \lambda h_{L_{fL_f}} \right) + (P_a)^2 \left( Y_{aI_aL_a}.G_{I_aE} \right)}{(P_a)^2 \left\{ Y_{aL_a} Y_{aI_aI_a} - \left( Y_{aI_aL_a} \right)^2 \right\} + P_a Y_{aI_aI_a} \left\{ P_f Y_{fL_fL_f} - \lambda h_{L_{fL_f}} \right\}} < 0 \quad (44)$$

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A representative household substitutes forest collection for agricultural activities. Equation (40) (ESM 1) shows that when the price of input used in agriculture increases, the cost of agricultural activities rises. The household in the peripheries of the forest tends to reduce the use of inputs.

Higher agricultural prices induce an increase in the number of inputs used. Due to agricultural intensification and the profitability of farming the households will engage in farming, which would lead to an increase in agricultural inputs. Equation (42) (ESM 1) indicates that at an increase in non-agricultural wages a representative household increases their labour supply in off-farm activities and reduces labour time in farming, which leads to a reduction in the use of agricultural inputs. Equation (43) (ESM 1) shows that the government income support program has a positive impact on the use of agricultural inputs. Any action of the government that leads to raising the income of the rural household tends to increase the inputs used in agriculture, which further raises agricultural production.

An increase in agricultural technical efficiency means that the same level of output will be produced using lower input. Thus, agricultural efficiency in the above equation shows that when agricultural efficiency increases, it has a decreasing effect on the use of inputs in agriculture. When the area under agricultural production increases, it leads to an increase in the use of inputs. The larger the area under cultivation, the higher will be the use of inputs. The scarcity of forest resources raises the shadow price of the forest, and the higher forest shadow price leads to lower labour supply in forest collection due to the increased opportunity cost of extraction. So, the higher shadow prices of forest reduce labour time in forest extraction and induce agricultural intensification that leads to an increase in agricultural inputs.

**Empirical analysis**

To test the theoretical relationship of the household model developed in Section 2 empirically, ideally one could use secondary data on the above variables. But the availability of the data at the national, regional or local scale, especially in the case of developing countries, is a big problem. For example, data on the number and quantity of forest products collected by the household over the time is not simply available, similarly like for all other variables. Data regarding the allocation of labour time can only be collected through an anthropological survey. For conducting an econometric analysis, we have collected information on the variable that is crucial for our theoretical model through a household survey. We are more confident that the harvest rate can be mostly explained by the exogenous variable in the model. Due to the data limitation, we have restricted our empirical model of forest product extraction to the following form.

$$Y_f = f(P_f, P_a, E_a, W_{OF}, I_a, \alpha_k, P_I, \lambda_f, Z_{cha}) \qquad (47)$$

The empirical model is defined as follows: the extraction of forest resources is a function of forest product prices, agricultural product prices, technical efficiency in the agriculture sector, input prices, shadow price of the forest, and wages in off-farm activities, level of knowledge about the forest resources, and household characteristics. From the theoretical model we know that forest labour supply is positively related to forest product supply, therefore it is expected that from the empirical analysis we get a similar relationship. Similarly, agricultural prices, technical efficiency, and off-farm wages negatively affect forest labour supply, in the same way we are hoping to get the desired results empirically.

The household's survey was conducted in the peripheries of the natural forests in the Malakand division of the Khyber Pakhtunkhwa (KPK) province, which lies in the northwestern part of Pakistan. KPK includes 40% of the natural forests of the country, playing an important role in the forestry sector of Pakistan. These forests mainly lie in two divisions, Hazara and Malakand.

The background knowledge of the socio-economic and demographic characteristics of the target region was considered when selecting the study area. This consideration led to the selection of six districts in the Malakand Division that are illustrated in Figure 2 (Buner, Lower Dir, Malakand, Shangla, Swat, and Upper Dir). Then, within this study area, new information on household interactions with forest resources was collected through questionnaires, which were structured according to six main topics: (1) household demographics; (2) agricultural output and type of cropland inputs commonly used; (3) fuelwood collection patterns; (4) type/quantity of non-timber forest products and other

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goods extracted from the forests; (5) sources of income; (6) timber extraction and transportation.

Information from 521 households in 23 villages was collected and analyzed to assess the relation of household characteristics with the likelihood of deforestation. Demographic variables of the households (HHs) considered were the family size, health and educational level of the household head whereas economic activities were examined through information on the major sources of income, the primary and secondary ones (e.g. agriculture as a primary income source with cattle ranching, off-farm activities, or external remittances as secondary sources).

The household is defined in this survey as "the people sharing the same house boundary wall and using the same kitchen or cooking and sharing meals". Before conducting the full household survey, a pilot survey was implemented in a randomly selected set of households among 3 different villages in 2 districts (Lower Dir and Malakand). This pilot took place during March 2017 and the full field survey was conducted in two periods: May–June 2017 and August–September 2017, using standardized techniques (Fowler, Mangione 1990) to minimize errors associated with the interviewing process. Additionally, basic data based on the location of forest and villages were obtained from the District Forest Office (DFO) and Range Forest Officer (RFO). The number of households interviewed in the integrated survey is 72 in district Buner, 84 in Lower Dir, while in districts Malakand, Shangla, Swat and Upper Dir it was 102, 89, 87 and 87, respectively.

Most of the households in all districts are primarily dependent on agriculture, followed by the sale of forest wood and NTFPs and daily wages. Agriculture is particularly important in Swat (75% of the households), followed by Upper and Lower Dir

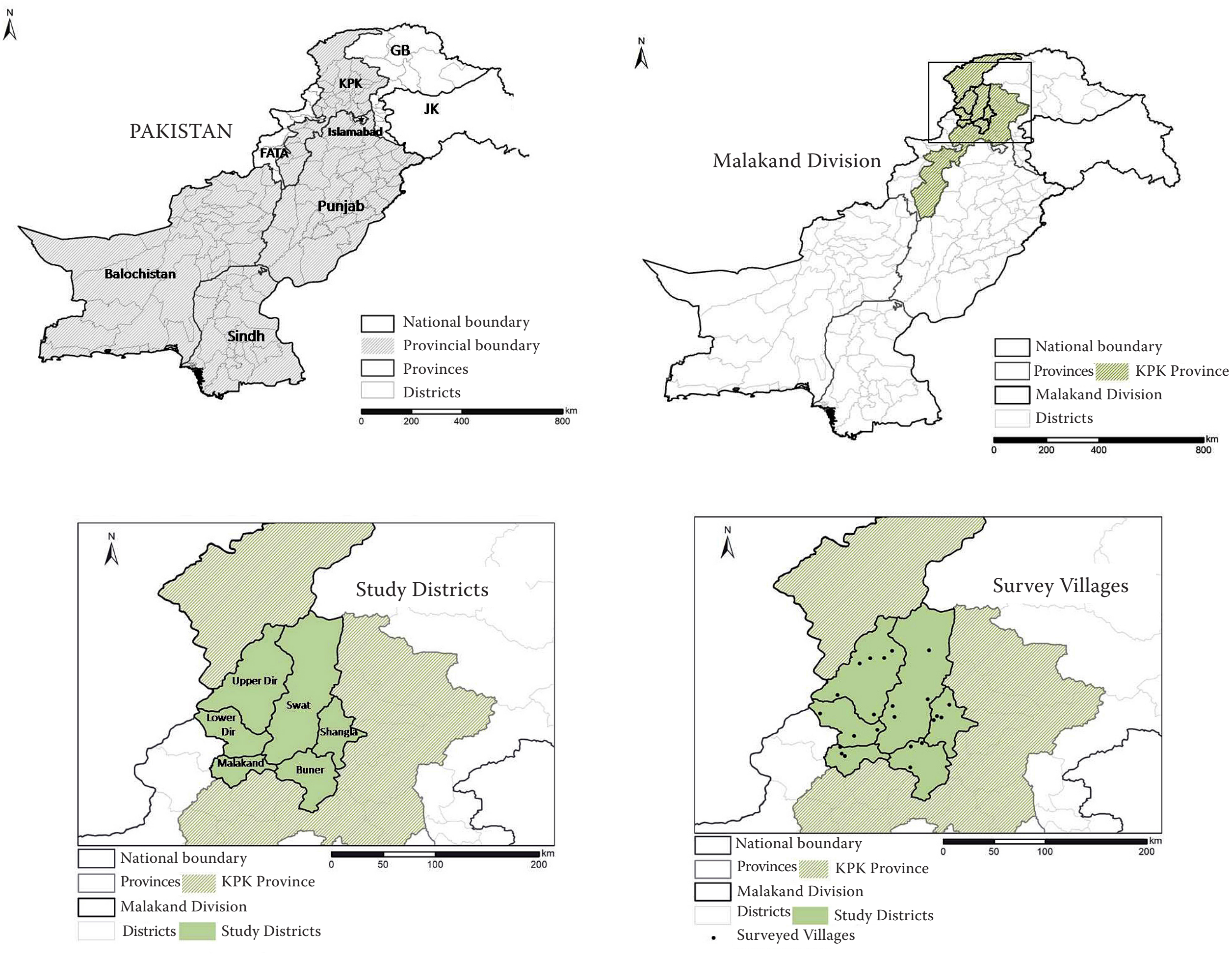


Figure 2. Study region

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Table 1. Sources of income of the representative households in the integrated survey (in %)

| Districts | Farming | Sale of wood and NTFP | Permanent jobs | Daily wages | Others |
|---|---|---|---|---|---|
| Buner | 40 | 26 | 8 | 15 | 11 |
| Lower Dir | 63 | 16 | 5 | 16 | 0 |
| Malakand | 41 | 12 | 5 | 22 | 20 |
| Shangla | 66 | 10 | 7 | 11 | 6 |
| Swat | 75 | 7 | 5 | 7 | 6 |
| Upper Dir | 56 | 14 | 7 | 13 | 10 |

The above percentage number is derived from the households investigated during the survey; others: a retired person from government institutions, family depending on remittances, and those families who have a small business; NTFP – non-timber forest product

(66% and 63% of the households depend on agriculture, respectively) (Table 1). The second most important source of income comes from the sale of forest products, especially in Buner. Malakand is the district with a higher proportion of households engaged in daily wage labour.

To estimate the Equation (47) variables input prices and shadow value of forest were dropped due to the lack of data, input price variable was dropped due to no variation in the prices of inputs across the households. In our survey, the representative household collects 15 types of forest and non-forest products consisting of timber products, vegetables, fruits, fodders, and medicinal plants.

The econometric valuation approach needs a dependent variable that measures how much a household depends on forest resources. In the literature forest product extraction by households is one of the ways to define forest dependency (Bluffstone et al. 2001; Pattanayak, Sills 2001). Nevertheless, there are complications in determining the time allocation for extraction. Similarly, the household trips to forest extraction do not necessarily reveal forest dependency. Forest dependency may also be defined in relative terms of forest share in total household income or as dummy variable but in all these cases no definition could reflect the magnitude of forest product extraction. Therefore, for this paper, we have used the total economic value of forest products extracted by the rural household during a year as an indicator of forest dependency (Table 2).

## RESULTS

### Income dependency results

A total of 521 observations were included in the empirical analysis. The average household size found 11.5 persons in the integrated survey. On

Table 2. Variables and measurement

| Name of the variable | Measurement of the variables |
|---|---|
| Forest income | Forest income is calculated through the monetary value of the sum of all products collected by the household during the survey year |
| Agricultural income | The monetary value of all crops produced by the household during the survey year |
| Household size | The total number of people living in the same house |
| Education of the HH's head | The education of the HHs was categorized from 0 to 5, where 0 = illiterate; 1 = read and write, 2 = primary, 3 = middle and high school, 4 = intermediate and college, and 5 = graduate and postgraduate. |
| Off-farm wages | The amount of cash received by the household working in non-agricultural activities including daily wage labour |
| Age of household head | Age of the household head to capture the resident duration in the village |
| Forest price (HH's level) | The price at which the household sells the forest products in local markets |
| Agricultural price | Agricultural price is collected as the average price of all crops produced by the household |
| Agricultural efficiency | It is calculated by using Data Envelope Analysis |

HHs – households

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Table 3. Tobit analysis of income generated from forest

| Forest income | Coefficient | Standard error | *t*-ratio | *P*-value |
|---|---|---|---|---|
| Age of household head | –0.3835 | 0.8280 | –0.460 | 0.643 |
| Household size | 5.5515 | 2.7102 | 2.050 | 0.041 |
| Educational level of HH | –23.823 | 7.3326 | –3.250 | 0.001 |
| Off-farm wages | –3.887 | 1.369 | –2.840 | 0.005 |
| Input price | 0.226 | 0.143 | 1.580 | 0.115 |
| Forest price (HH's level) | 33.659 | 7.101 | 4.740 | 0.000 |
| Agricultural price | –7.658 | 21.067 | –0.360 | 0.716 |
| Agricultural efficiency | –89.088 | 51.554 | –1.730 | 0.085 |
| Constant | 44.1145 | 58.611 | 0.750 | 0.452 |

No. of observations: 521; $F$-stat(8 513) = 6.73, Prob($F$)= 0.000; HH – household

average 60% of the households showed agriculture as the primary source of income, followed by 15% of sales of forest production and non-timber forest products, and 14% of daily wage labour. About 61% of the household heads showed themselves illiterate, 22% of the households had basic primary education, while 10% and 7% of the households got matriculation and a college degree. Out of the 521 households in the survey, 28% reported that they do not extract forest products, either timber products or non-timber forest products. So, in this case, estimating Equation (72) (ESM 2) through Ordinary Least Squares (OLS) with zero for the households that do not collect forest products gives inconsistent estimates while taking out the observation with zero value from the empirical analysis leads to sampling selection bias (MacDonald, Moffit 1980). Therefore, tobit regression analysis was used to get the empirical results.

The results above in Table 3 are consistent with the theoretical finding of the household model. Agricultural efficiency shows a negative and statistically significant relationship with forest extraction. The result suggests that increasing agricultural efficiency has a decreasing effect on forest resource extraction. The result of off-farm wages is consistent with the theoretical model, showing a negative relationship between off-farm wage rate and forest resource extraction. Similarly, forest product prices and household size are positively related to forest resource extraction, higher forest prices encourage forest resource extraction while with the larger household size the probability of forest extraction is also high. Like in the theoretical model, the effect of agricultural prices on forest product extraction was also proved empirically, the higher agricultural prices can lead to lower forest extraction. The result of input price shows a positive relationship with forest dependency, but the relationship found was statistically insignificant. Finally, the educational level of the household was found statistically significant and consistent with the theoretical model. The higher educational level of the household decreases forest resource extraction. The education of adults not only improves agricultural production techniques but also provides an understanding of forest existence for environmental sustainability.

**Consumption dependency results**

Consumption dependency is defined as the household that is dependent on forest goods either for food products or for fuel energy. The variable is constructed by adding the monetary value of all the products a representative household used during the survey year. The result of the empirical model is quite consistent with the relationship that exists in the theoretical model (Table 4). Both forest and agricultural prices are negatively related to the consumption of forest goods. The logic behind the negative relationship between agricultural prices and forest product consumption is that higher agricultural price leads to higher family income, a household with higher income will look for energy and food substitution. While higher forest prices lead to lower consumption of forest goods as fuel or food as forest products become expensive to purchase. The result of off-farm wages is also consistent with the theoretical relationship and statistically significant, when the wages in off-farm activities increase, consumption dependency on

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Table 4. Tobit analysis of the consumption of forest production at home

| Forest products consumed by household | Coefficient | Standard error | $t$–ratio | $P$–value |
|---|---|---|---|---|
| Age of household head | –13.96 | 231.49 | –0.060 | 0.952 |
| Household size | 3.482 | 0.6150 | 5.660 | 0.000 |
| Educational level of HH | –1.163 | 1.3025 | –0.890 | 0.372 |
| Off–farm wages | –0.619 | 0.250 | –2.480 | 0.014 |
| Input price | 0.089 | 0.037 | 2.390 | 0.017 |
| Forest price (HH's level) | –4.665 | 1.414 | –3.300 | 0.001 |
| Agricultural price | –16.213 | 8.621 | –1.880 | 0.061 |
| Agricultural efficiency | –48.545 | 15.229 | –3.190 | 0.002 |
| Constant | 144.131 | 18.653 | 7.730 | 0.000 |

No. of observations: 521; $F$–stat(8 513) = 10.08; Prob($F$)= 0.000; HH – household

forest resources decreases. Similarly, agricultural efficiency and the age of the household head show a negative relationship with forest resource extraction for consumption purposes. The result of input prices which comes out consistent with the theoretical model previously for income dependency was insignificant with a positive sign. While in the case of consumption dependency a consistent and statistically significant relationship was found for input prices and forest resource extraction. Finally, the literacy of adults was also found consistent with the theoretical model, the higher educational level of the household leads to lower dependency on forest resources. Household size was again found positive and significant with forest resource extraction.

## DISCUSSION, CONCLUSION, AND POLICY RECOMMENDATION

Traditionally, the drivers of deforestation and forest degradation are classified into two groups. First, the forest cover loss from conversion to other land uses such as agriculture and pasture by the endogenous people (Barbier 1993; Kissinger 2012; Meyfroidt et al. 2013). Second, much of the forest land converted to barren land due to excessive timber logging and collection of forest resources for commercial and subsistence uses (Repetto 1990; Geist, Lambin 2002; Chowdhury 2006). Agricultural expansion is still one of the major causes of deforestation across the developing world such as Brazil, Indonesia, Malaysia, and South Asia (Hosonuma et al. 2012). But, in many developing countries including Pakistan the forest area declined to the lowest level and subsequently got the notion of protected forest. Therefore, the expansion of agriculture and pastureland becomes more restrictive than the extraction of forest and non-forest resources by the endogenous communities.

The household time allocation model results suggest that any governmental policy that increases the productivity and profitability of the agriculture sector leads to the higher equilibrium stock of both timber and non-timber forest resources. The results from empirical analysis confirm the dynamic predictions from the theoretical model. From the policy point of view, both empirical and theoretical models suggest that the conservation of forest resources must be complemented by the development of agriculture sector in the peripheries of the forest. The intensive effort is to be made to stimulate farming in the forest localities along with some measures to avert the forest land conservation into agriculture. This may induce localities to decrease their dependency on forest resources.

To compare the proposed policy with the Integrated Conservation and Development Project (ICDP) for forest conservation by the United Nations has several advantages. The central idea of ICDP is to promote forest conservation through traditional thinking, involve in income generation activities for the rural communities through less harmful ways for their livelihood (Barret, Arcese 1995; Simpson 1995; ). Apart from this, if the ICDP strategies are successful commercially and the local communities get compensation for the income loss from the forest protection, whether the rural households will protect the forest voluntarily remains an open question. Previous experience indicates that such approaches have not produced

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sufficient local income e.g. the studies of Simpson (1995) and Simpson et al. (1996) suggest that income generated by forest resources is likely negligible like payments in the form of royalties and upfront payment usually go towards the collector and only a marginal part of the revenues from the ecosystem may occur in the hands of local people. While taking the example of eco-tourism, the utmost of the expenses acquired from the visitors goes to the airlines, hoteling, and other services. Consequently, a small portion of the expenditure may be spent on the site while huge revenue generated by the ecosystem goes away from the local communities. Due to a lack of infrastructure, institutions, and skilled persons at the local level, a significant portion of the revenue cannot be captured. Therefore, activities like eco-tourism, biodiversity prospecting may not produce sufficient income at the local level, may not offer motivations for the rural communities to protect the forest. Hence, agriculture-oriented support policy, on the other hand, will provide the opportunity to divert labour force from the forest activities to agriculture, thus, it will reduce forest dependency.

This study suggests that the mechanization of the agriculture sector in the peripheries of the forest may alter the conservation of forests. For the policy perspective, we suggest a joined approach to achieve the objectives of forest conservation through the development of agricultural activities and alternative income generation opportunities. This approach will reduce the cost of forest monitoring because the forest departments in the developing countries are not well equipped and there is also a lack of resources and skilled manpower to undertake this task (Leader-Williams et al. 1990; Barret, Arcese 1995). Indirectly, the study gives environmental justification to reduce poverty in the forest peripheries to conserve natural resources and promote environmental sustainability.

There may be a possibility of a negative outcome of encouraging agricultural activities as an alternative to conserve natural resources by the fact that the high profitability of farming leads to encroachments into the forest land. Nevertheless, such a negative outcome should be minimized through the implementation of policies that encourage agricultural activities along with a legislative measure to avert the transformation of forest land to agriculture. Sometimes, high profits from farming attract people from other regions and localities, which could further intensify the pressure on forests and reduce the benefits from the suggested policy.

The gap for future research, the two main restrictions (land allocation between forest and agriculture is kept exogenous) made in this paper can be relaxed. Taking these land-use decisions as endogenous may produce different results. The relationship between deforestation and encroachment can be studied dynamically through a model in which agricultural development leads to the lower extraction of forest products while, on the other hand, it increases encroachment and forest land clearing. Then the area and stock of forest can be obtained from the optimal point (equilibrium). In such a scenario, agricultural development policies can benefit the rural communities while encroachment reduces the optimal stock of forest. Therefore, it will be very interesting to explore the properties of such equilibrium.

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