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Towards a Theoretical Construct for Modelling Smallholders' Forestland-Use Decisions: What Can We Learn from Agriculture and Forest Economics?

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Abstract: Academic research on smallholders' forestland-use decisions is regularly addressed in different streams of literature using different theoretical constructs that are independently incomplete. In this article, we propose a theoretical construct for modelling smallholders' forestland-use decisions intended to serve in the guidance and operationalization of future models for quantitative analysis. Our construct is inspired by the sub-disciplines of forestry and agricultural economics with a crosscutting theme of how transaction costs drive separability between consumption and production decisions. Our results help explain why exogenous variables proposed in the existing literature are insufficient at explaining smallholders' forestland-use decisions, and provide theoretical context for endogenizing characteristics of the household, farm and landscape. Smallholders' forestland-use decisions are best understood in an agricultural context of competing uses for household assets and interdependent consumption and production decisions. Forest production strategies range from natural regeneration to intensive management of the forest resource to co-jointly produce market and non-market values. Due to transaction costs, decision prices are best represented by their shadow as opposed to market prices. Shadow prices are shaped by endogenous smallholder-specific preferences for leisure, non-market values, time, risk, and uncertainty. Our proposed construct is intended to provide a theoretical basis to assist modellers in the selection of variables for quantitative analysis.

Keywords: transaction costs; separability; afforestation; international development; modelling

1. Introduction

Smallholders' forestland-use decisions have important environmental and economic implications. There are an estimated 1.2 billion smallholder farmers that grow trees or manage remnant forests on their land [1,2] making them arguably the most numerous type of forest manager in the world. Additionally, the greatest area of land available worldwide for new afforestation initiatives takes places on farmland [3] and smallholders own 85% of the world's farms [4]. From an economic perspective, smallholders' forestland-use decisions play an increasingly important role on timber and fuelwood supply. As the area of forests worldwide continues to decline, timber in many low-income countries comes primarily from farms rather than forests [5] and smallholder-produced wood-energy generates more value than several of the world's largest oil and gas companies [6]. This has important livelihood implications given that an estimated 2.4 billion people in low-income countries depend on wood to cook their food, boil their water and build their homes, not to mention the contribution this makes to the creation of millions of jobs in the formal and informal sectors [7]. From an environmental perspective, smallholders have afforested more land worldwide than the corporate sector while planting a much greater variety of species [8]. This leads to an increased supply of numerous environmental services such as biodiversity, watershed protection, nutrient cycling, reduced topsoil erosion, wildlife habitat, etc. [9]. These afforestation initiatives are also particularly important given that deforestation is a major contributor to anthropogenic greenhouse gas emissions [10]. For these reasons, there is great value in understanding how smallholders make their forestland-use decisions.

There are three streams of forest economic literature that make important contributions to theoretically conceptualizing how smallholders make their forestland-use decisions. The first is the foundational forest economics literature based on maximizing the land's expected value [11], from which most of the traditional forest economics profession is based. This literature is anchored in the neoclassical theory of the firm where land-use choices are made based on optimizing discounted cash flows from exogenous market prices [12]. This literature has been extended to include smallholder participation in afforestation programs where the general emphasis is on environmental services, poverty alleviation and how much institutions need to pay to incentivize smallholders to plant trees on their farms [13]. The second stream is related to forest management decisions such as timber harvesting, reforestation, and silvicultural treatments of non-industrial private forest landowners (NPFL) [14]. In this literature, trees are recognised to have a number of unique characteristics, notably their inherent joint production of market and amenity values (i.e., non-pecuniary benefits or non-market values such as aesthetics, recreation and wildlife habitat) [15] that influence land-use decisions and correlate with landowner preferences [16]. While developed and empirically tested in the forests of some of the most economically developed countries in the world where markets work reasonably well, this stream has occasionally been extended to include smallholders' forestland-use decisions in low-income countries where market friction is notoriously high [17]. The third stream focuses on smallholders' adoption of agroforestry practices. This literature is generally concerned with the diffusion of improved land-use practices. Pattanayak et al. [18] reviews 120 articles on adoption of agricultural and forestry technology by smallholders and categorizes explanatory variables based on numerous household and farm characteristics into broad economic categories that explain behaviour. However, as we argue in this article, each one of these streams is incomplete on its own.

The objective of this article is to build a theoretical construct for studying smallholders' forestland-use decisions. Our construct is intended to serve in the guidance and operationalization of future models for quantitative analysis. It does not prescribe specific dependent or independent variables to be used in a model nor does it recommend any specific functional form. Rather, our construct provides a conceptual basis to assist modellers in the selection of appropriate concepts depending on the context of their study and their specific research questions. Different variables can then be used as proxies for these concepts directly in a model or sub-model. Our construct also provides theoretical guidance for the interpretation of independent variables related to the household, farm and landscape that are commonly found to be statistically significant in studies relating to smallholders' forestland-use decisions. The methodological justification for developing a theoretical construct, as opposed to a model, is that models are self-contained and cannot tell us what phenomena are worth modelling. Theoretical constructs include elements that are not necessarily directly observable whose influences can nonetheless be captured, at least partially, through models [19].

Our theoretical construct is inspired by the last 200 years of forestry research focused on Faustmann's theories of land-use decisions and the more recent literature on NPFL. However, in the smallholder context, trees in farming systems are more accurately seen not as a part of the forest resource but rather part of farm household livelihood needs and strategies. As such, the field of agricultural economics, particularly agricultural household models, offer 40 years of empirical research specifically designed to explain the land-use choices of small family-owned and -managed farms that consume important proportions of their own production (i.e., smallholders) [20]. Together, these two fields offer important insights into smallholders' forestland-use decisions. However, the two disciplines evolved in very different contexts from different underlying theories conceived for different purposes, making them both incomplete as a theoretical construct for smallholders' forestland-use decisions. While this paper is not a historical account of the two disciplines, the evolution of some of the ideas is explored to better understand their similarities, divergences and to argue why neither of them is independently fully applicable to the context of smallholders' forestland-use decisions.

A crosscutting concept to our theoretical construct is how transaction costs drive separability (i.e., independence) between consumption and production decisions. While this concept has become the trademark of agricultural household models [20] and a common feature in some of the literature on NPFL, making it explicit justifies the endogenous nature of household characteristics, their farm and the landscape. This contrasts with industrial forestry and earlier agricultural household models where the only relevant variables to land-use decisions are exogenously determined production technologies and market prices. In such models, based on a profit maximizing objective function, households first determine the quantities of inputs required for the profit maximizing levels of production and then decide how much of those inputs to supply using household assets versus the marketplace based on their preferences. Differences between the households' demand for the profit maximizing quantities for factor inputs and outputs, and their supply of those same inputs and outputs are considered perfect substitutes that can be traded in the marketplace at prices that guide land-use decisions such that household preferences do not actually shape land-use decisions. However, in the presence of transaction costs, a wedge is created between the market price and the decision price (i.e., shadow price) such that production and consumption decisions are no longer independent. Consumption and production decisions become interdependent, preferences matter, and previously exogenous variables become endogenous to the model.

Our theoretical construct is built using the same core economic elements employed by industrial forestry land-use models and earlier agricultural household models. These core economic elements are the objective function (Section 2), the production function (Section 3), and the prices for factor outputs (Section 4) and inputs (Section 5). However, given the presence of transaction costs, decision prices for household- and market-supplied factor inputs and outputs are no longer perfect substitutes, which is particularly relevant for smallholders given that they supply and demand a significant proportion of their own factors of production. As such, in our theoretical construct, smallholders also choose consumption bundles based on decision prices shaped by an endogenous set of household, farm and landscape characteristics for factor outputs produced by the joint production function of trees for non-market environmental services (Section 4.1) and environmental services for which markets commonly exist (Section 4.2). Smallholders also choose consumption bundles that provide them with the highest utility based on shadow prices shaped by their endogenous set of preferences for the following factor inputs supplied by the household: labour and leisure (Section 5.1), time (Section 5.2), land (Section 5.3), risk (Section 5.4), and uncertainty (Section 5.5).

We establish a number of boundaries to the applicability of this theoretical construct. First and foremost, this construct is developed with the perspective that economic principles shape human behaviour. We do not explore human decision-making from an anthropological, sociological, political or other perspective. Second, this theoretical construct is uniquely concerned with the smallholder context. Smallholders are defined as farmers in low-income countries that operate family-run farms using largely their own household labour, and that are weakly connected to markets (i.e., face disproportionately high transaction costs). This formally excludes industrial forestry or small-scale forestry in contexts where transaction costs are low [11]. Third, this construct is uniquely concerned with privately owned smallholder land. This excludes smallholders' management of collectively owned lands such as public or cooperatively owned land. Therefore, we do not address the growing literature on collective decision-making for the management of natural resources [21–23]. Fourth, this theoretical construct remains at a very high level, focusing on the core economic elements of the objective function, the production function, and decision prices for household-supplied and -produced factor inputs and outputs in the presence of transaction costs. We do not focus on the origin of preferences and transaction costs nor the strategies used by smallholders to manage transaction costs but rather the role of preferences on decision prices themselves. As such, we exclude the literature on embeddedness, the larger structures that embed economic transactions that include formal and informal institutions, customs and traditions, norms and religion, which are known to shape preferences and transaction costs [24]. Most notably, the concept of embeddedness includes trust and social capital, which facilitate coordination and cooperation to pursue shared objectives [25]. For example, in developing countries where institutional and market failures are more common, concepts of embeddedness have been shown to reduce the effects of transaction costs by, for example, helping overcome labour resource constraints through labour-sharing arrangements [26], reducing information market inefficiencies (i.e., uncertainty) by facilitating the flow of information [27,28] and to relax financial constraints [29]. While embeddedness shapes the core economic elements covered in this study, it is a lower order construct and therefore excluded. Finally, to limit the scope of this work, we do not address the many factor inputs that are not fundamentally different in the smallholder forestry context. For example, we do not focus on the use of factor inputs not directly produced by the household such as fertilizers nor the current state of production technologies other than acknowledging their influence on production. Nonetheless, we hope that future research can expand this theoretical construct to study these phenomena and the effect that they have on the core economic elements we discuss.

2. The Objective Function

Modelling smallholders' forestland-use decisions requires the use of an appropriate objective function. The objective function defines the guiding principles of smallholder production, generally based on maximization regardless of whether or not that is actually achieved. In the broader economic literature, the theory of the firm is concerned with profit maximization and consumer theory is concerned with utility maximization [30]. Profit is derived from financial values associated with production whereas utility is derived from various values associated with consumption. The challenge is that smallholders are consumer-producers; in effect, smallholders are both mini-firms that produce forestry and agricultural goods based on profit motives, and households of consumers and factor suppliers operating on utility motives.

In this section, we provide a starting point to our theoretical construct for smallholders' forestland-use decisions by highlighting the origins of the objective function in forestry economics and agricultural household models. Both started from a perspective of profit maximization and periodically converge towards utility maximization but by focusing on different values. Forestry economics has most commonly relied on simulations whereas agricultural household models have most commonly relied on econometric specifications, largely because they were conceived to address different research questions for different types of entities. Understanding these different origins offers valuable insights for our theoretical construct.

2.1. From Profit to Utility Maximization

2.1.1. Agricultural Household Models

Agricultural household models evolved from a system of equations approach from the broader economics literature, particularly the neoclassical theory of the firm. Firms are defined as entities that make production decisions. The objective function of the firm is to maximize profits, which is achieved by employing quantities of factor inputs until their marginal benefits are equal to their marginal costs [30]. A firm's profit function consists of a revenue function and a cost function. Revenue is defined as the price of outputs multiplied by their quantity as determined by the production function. The production function describes the transformation of a set of inputs into outputs. The cost function describes the costs of production for a given quantity of outputs. To maximize profits, a firm needs to find the lowest production costs for a given value of output. In McFadden's [31,32] seminal work on the duality of cost, revenue and profit functions, he noted that in the short-run, provided that firms are price takers and profit maximizers, profit functions or cost functions contain all the relevant economic information to recover a firm's production function. This insight had important implications for agricultural economists because a firm's production function is difficult to measure directly whereas costs and quantities are commonly available economic data. In the smallholder context, if farms are viewed as mini-firms with the objective of maximizing profits, profit functions could be estimated and land-use allocation decisions should be predictable [33,34].

A first generation of agricultural household models designed for econometric specification was born. Such early models recognized that smallholders are also consumers but did not treat that distinction as important. According to standard microeconomic theory, the behaviour of consumers is governed by different principles than those of firms [30]. Consumers are not profit maximizers; they are motivated by utility, which they try to maximize subject to their endowment or budget and their preferences. However, through what is known as the separability assumption, household consumption motivated by utility and household production motivated by profits are independent. When this is the case, households that consume their own production (e.g., labour, leisure, food, etc.) are implicitly purchasing it from themselves at the market price. As such, if a household does not want to supply the profit maximizing quantities of factor inputs due to preferences, they can purchase them at the market price. If a household wants to supply more than the profit maximizing quantities of inputs required for their own farm, they can sell that surplus in the market (e.g., labour). The household maximizes profit and then maximizes utility subject to a standard budget constraint which includes the value of these profits [35]. Smallholder behaviour is still guided by preferences but such preferences are assumed unimportant to production and therefore land-use decisions. However, it soon became apparent that such models struggled to explain counterintuitive behaviour and a second generation of agricultural household models evolved that integrated the interdependence of consumption and production decisions.

A new generation of agricultural household models quickly evolved for when markets no longer clear without friction. This is particularly important for smallholders since they are commonly located in rural areas in low-income countries where transaction costs are notoriously high and they supply important proportions of their factor inputs and consume important proportions of their factor outputs. Under such circumstances, the separability assumption no longer holds and production decisions depend on a household's unique set of preferences and endowments. Consequently, agricultural household models started integrating endogenous characteristics of the household and their farms when analyzing rural economies since they are related to preferences and endowments [20,36]. Earlier models focused primarily on friction in land and labour markets [37,38] but they evolved to formalize numerous other factor inputs, outputs and transaction costs in the models that are commonly used today [39], all of which is valuable for smallholder forestry. However, none of these agricultural household models considers many of the unique attributes of forestry.

2.1.2. Forest Economics Land-Use Models

The field of forest economics has a long pedagogy with the principle that forestland-use decisions are based on profit maximization, known as maximizing the land's expected value (LEV). While not the first to apply discounting in the forestry literature [40], Martin Faustmann [41] has become known as the founding father of neoclassical forest economics. In Faustmann's view, forestry was a type of agriculture with a particularly long planning horizon [41]. Faustmann's model discounts a stream of revenues from the sale of timber by an interest rate from the time of harvest to the present minus the cost of afforestation [42]. The interest rate is the rate at which capital can be borrowed in the marketplace. The optimal time of harvest, as demonstrated by Pressler [43] using the Faustmann model, is when the rate of change in timber value with respect to time is equal to the forgone interest on the value of the standing timber plus the forgone interest on the value of the land. The investment valuation using the Faustmann model occurs before the investments are made and should be considered on land suitable for forestry where there are competing land-uses such as agriculture. Even in Faustmann's Germany, fast-growing exotic tree species were promoted to increase the competitiveness of forestry [42]. When the LEV is used for a perpetual periodic series of harvests, it is equivalent to the net present value (NPV), one of the primary investment decision criteria used today. To this day, the Faustmann model remains the primary valuation method for privately owned forestland and, in many economic circles, Martin Faustmann is attributed to being the founder of capital theory [44]. To the pride of forest economists, discounted cash-flow models were published over 100 years before Irving Fisher [45,46] "discovered" the same concept and introduced it to the non-forestry economics profession.

Faustmann's relatively simplistic model has been expanded to handle many real-world complexities using complex simulations. While it was developed for clear-cuts of even-aged single species, authors have developed optimizations for uneven-aged stands [47], uneven-aged management [48], mixed-species forests [49], natural regeneration [48] and declining site productivity [50]. Non-timber forest values are increasingly assigned prices in decision making and integrated into the Faustmann model using joint production functions, notably for carbon sequestration [51,52]. Yields at the time of harvest are not pre-determined, as they inevitably entail a degree of risk from natural hazards such as pests, fire, storms, etc. Therefore, various authors have expressed timber yield as a probability distribution as opposed to a deterministic value [53,54]. Similarly, the prices of future factor inputs and outputs are also unknown at the time management decisions are made. As such, authors have integrated changing or stochastic pricing into the model for timber [55], carbon [56], interest rates [57] and reservation prices [49]. Given the stochastic nature of forestry investments, some authors integrate real option theory into forest valuation [56,58]. Others have focused on integrating the effects of taxation [59] and multiple product classes [60].

The neoclassical theory of the firm is well suited to the discipline of forest economics given its historical evolution as an industrial discipline but it is not well suited to smallholders. Empirical tests of the LEV and its opportunity cost show that it is not effective at explaining smallholders' forestland-use decisions [61], their management of tree resources [62] nor their willingness to accept compensation to afforest their land [63]. While some might interpret this as a shortcoming of the theory, it is arguably more the case that the theory is being used outside of the context for which it was designed. The discipline of forest economics was not developed to address the needs of smallholders' forestland-use decisions.

By the late 1970's it became clear that many forest owners were guided by different principles than those of profit maximization. Clawson's [64] book titled *The Economics of US Nonindustrial Private Forests* generated a surge of research into the management decisions of private individuals that controlled the majority of forested area in the country [65]. A literature quickly emerged on the management decisions of what has become known as non-industrial private forestland-owners (NIPFs). Originally, models were developed to predict timber supply but they evolved to include other forest management decisions such as reforestation [66,67]. A key distinction as compared to industrial models is that behaviour was conceived to include utility (which includes profits and other values) as opposed to just profit maximization largely inspired from agricultural household models but with a very different approach to production functions, as later described in Section 3.

The literature on the economics of forestland-use decisions evolved in some of the most developed countries of the world with little explicit recognition of the interdependence of consumption and production decisions in forestry and agriculture. This is because smallholders are commonly located in rural areas in low-income countries where transaction costs are notoriously high and they supply important proportions of their factor inputs and consume important proportions of their factor outputs, all of which play an integral role in the specification of the objective function.

3. The Joint Production Function: Market and Non-Market Values

The production function, which describes the transformation of inputs into outputs, is intimately related to the objective function and arguably explains the greatest divergence between agricultural household and forest economic land-use models. Agricultural production functions are commonly generalized and quantitatively estimated using relatively simple functional forms such as a Cobb-Douglas function (e.g., [68]) or reduced form models (e.g., [69]). Management decisions, including the actual crop being grown, are given less importance and commonly considered endogenous variables. Emphasis is placed on supply responses to changes in the exogenous macro-economic environment (e.g., changes in technology and prices). Contrarily, forestland-use models use relatively complex production function (e.g., [48]) as an entire sub-discipline, commonly referred to as growth and yield. The volume of timber produced is based on a production function usually subject to the trees' genetics, management interventions, and the site productivity index of the land including precipitation, soil structure, slope, aspect of the land, temperature, etc. After trees are planted, they become an exogenous part of the production function so a heavy emphasis is placed on selecting the quantity, quality and timing of silvicultural management to maximize profits as a function of exogenous and dynamic market prices.

An important contribution from the field of forest economics to smallholder forestry is the joint production of market and non-market values of trees. This is because trees produce numerous environmental services (i.e., ecological processes or functions that have value for people [70]). In the absence of transaction costs, exogenously determined market prices for these environmental services simply need to be integrated into land-use models. The problem is that markets rarely exist for many of the environmental services and when they do, transaction costs tend to be disproportionately high.

For smallholder forestry, the joint production function of the tree-based component of a farm can be thought of in three different ways depending on the context. The first way, such as conceived by Faustmann, is the intentional cultivation of trees for the market outputs that they provide (e.g., timber, carbon, etc.) but that also include non-market values. Specific species are selected and cultivated in specific locations at specific moments in time for specific purposes. In this context, appropriate modelling approaches include estimating a production function based on growth and yield models from forestry science while also considering the yield of relevant environmental services valued by the household. The second context is the intentional cultivation of trees as part of the farm's cost minimization strategy through the services that they provide. Such services can be thought of as inputs into the agricultural production function. This generally includes leveraging positive on-farm interactions that support other agricultural activities such as fertilization through the use of nitrogen fixing trees and mulch creation, forage for livestock, or functional support from multipurpose species in the form of trellises, barriers, shade, soil retention, etc. In such cases, an appropriate modelling approach might integrate these services into the cost or profit function of agricultural crops. Finally, there is the non-intentional or passive cultivation of trees on farms. This is because trees commonly regenerate naturally; they grow on land that is not farmed. The costs of growing trees in many contexts are negligible; rather there are costs associated with preventing them from growing in the first place. To keep cattle pastures as pastures, smallholders regularly clear trees year after year so that their fields do not revert back to forest. On non-arable or fallow portions of the farm, trees also grow naturally until the land is cleared again for new agricultural land-uses. Such cleared trees form the basis of fuelwood supply in many tropical regions throughout the world [71]. This natural or wild growth of trees commonly makes them a sort of semi-open access resource where trees can be gathered (as opposed to produced) from public forests, the private property of others or even naturally occurring trees on a smallholders' own farm. Appropriate modelling approaches for the production function where the trees come from a farmer's own farm might be the inverse of agricultural land-use decisions. In cases where the wood is gathered from off the farm, the production function becomes focused on the costs incurred harvesting and transporting the wood to the market or the point of self-consumption (e.g., the fireplace). While these three conceptualizations of the production function of trees are presented as discrete categories, they represent a portfolio, from which smallholders and therefore modellers may choose multiple approaches. For example, a common strategy for smallholders when clearing trees from fallow land that naturally regenerated is to leave the occasional high-value species alive until they reach merchantable size. Regardless, recognizing these different approaches to afforestation is particularly important when trying to model smallholders' forestland-use decisions.

4. Endogenous Shadow Prices of Market and Non-Market Values

Exogenous market prices for outputs are perhaps the most important type of variable used in agricultural household and industrial forestry models. However, given the joint production function of trees and the presence of transaction costs, market prices are not likely to be appropriate proxies for decision prices. In this section, we provide an alternative conceptualization for the shadow prices of forestry outputs that can be endogenized into smallholder forestland-use models.

4.1. Non-Market Values

Non-market values are not unique to the field of forestry but their relative contribution towards total economic value is. For example, from the agricultural literature, indigenous farmers in Mexico sometimes have cultural values associated with heirloom varieties of maize and therefore prefer producing their own as opposed to buying it from the market even when the market grain is cheaper [72]. In such cases, the total economic value of the corn is its market price combined with the preference-based value placed on the non-market values that it provides. This effect is similar to growing trees for the commodity value of the timber while enjoying the aesthetic beauty of the forest. However, growing a forest entirely based on non-consumptive non-market values is common whereas in agriculture it is not.

Trees have a number of characteristics that lend themselves well to non-market values that merit consideration in smallholders' forestland-use models. Size is perhaps the most important characteristic, with trees being the largest plants in the world in terms of height, diameter and area (i.e., crown cover). Tree size has been found to significantly increase people's willingness to pay for keeping them alive [73] and their demand for recreation sites [74]. Longevity is also very important, with some living trees reported to being over 5000 years old. While most trees do not live anywhere near this long, their ability to live longer than humans seems to play a special role in determining non-market value. The age of a tree is highly correlated with tree size but age in its own right provides certain unique values. Trees' age combined with their size provide for long-lasting structures that modify microclimate, create habitat that host some of the most bio-diverse terrestrial places on earth, and represent living cathedrals for peoples from around the world. Older trees are commonly associated with different historical periods, and their longevity facilitates inter-generational transfers of value or even markers of land tenure. Trees are an important tool for inter-generational transfers, and such transfers are an important aspect of the literature in both forestry and agricultural economics [75,76].

The integration of joint-production models follows Hartman's [77] seminal description of why and how amenity and other non-market considerations affect forestland-use decisions. The theoretical foundations to this work are based on timber supply models using the first-order conditions of a typical constrained maximization problem to be a function of market prices, socio-demographics, and forestland characteristics [78,79]. The key difference compared to LEV models is that forests provide utility from the joint production of timber for the marketplace in addition to amenities (i.e., non-pecuniary benefits such as aesthetics, recreation and wildlife habitat) or environmental services for which markets do not exist but that nonetheless have value, and that such utility is endogenous to the household [15]. The challenge is that many of these environmental services and people's preferences for such services are unobservable and therefore difficult to measure. Consequently, researchers generally look to use observable proxies related to landowner characteristics [66], landowner behaviour [80,81] or forestland characteristics [66], or methods of stated preferences [82]. Rarely do researchers attempt to actually assign shadow prices to such values.

4.2. Market Values and Endogenous Location

Market values for provisioning environmental services such as food, fuel and fibre are fundamental to the theory of how land-use decisions are shaped in agricultural and forestry economics. In practice, the market price of agricultural outputs is generally statistically significant in agricultural household models yet in smallholder forestry models, this is rarely the case. In a review of 32 smallholder forestry adoption studies, prices were only significant 6.4% of the time [18]. This suggests that market prices are commonly too low to have an effect on behaviour or that transaction costs are disproportionately high in tree product markets such that observable market prices are no longer appropriate proxies for unobservable shadow prices. When this is the case, the endogenous location and characteristics of the landscape become particularly important elements in shaping shadow prices and therefore land-use models.

In the forestry literature, transaction costs considered generally include issues relating to compliance with forestry laws such as the costs involved in getting the necessary permits to harvest trees, to transport the wood [83] or the costs related to enforcing property rights [84]. However, as we argue, disproportionately high transportation costs also need to be considered. While it might seem obvious that transaction costs along the value chain such as transportation need to be included, confusion arises from the modeller's perspective when specifying what precisely consists of a transaction cost since one firm's transaction costs are another firm's production costs. For example, search and information costs, a classic example of transaction costs, is the core production cost of a marketing intelligence firm. Therefore, transaction costs should more accurately be thought of as a function of how a product (or service) is defined including its physical characteristics but also concepts of space and time. If a tree product were defined as a log at the point of sale at a specific date, growing the tree, harvesting and transporting it would be considered production costs. Alternatively, if the product were defined as a standing tree, growing the tree would be a production cost whereas harvesting it, transporting it to the market and storing it until the time of sale would be considered transaction costs. Given the focus on forestry production irrespective of the final product and the structure of its supply chain post-production, it makes sense to conceptualize the value of trees at the farm gate or as a standing tree (i.e., stumpage value) even when market prices are not available. The challenge is assigning a shadow value.

Distance is particularly important for tree products since it greatly limits the distance that wood can be transported cost effectively. This phenomenon is highlighted by the low product value density (PVD) of wood. PVD is simply the value of a product divided by its weight (sometimes called the value to weight ratio), which limits the size of the total addressable market [85]. For smallholders, this means that the market price minus transportation costs is highly affected by the distance between their farm and the market. Even though the total size of the market for wood products such as fuelwood and timber is large, very little of it, if any, can be accessed cost effectively for many smallholders. As a reference, coffee in Nicaragua is an internationally traded commodity with a PVD of ~$3.05/kg. Sorghum is one of the lower valued agricultural crops in Nicaragua and has a PVD of ~$0.28/kg, which is less than 10% of that of coffee. Despite being a crop of international importance, sorghum is rarely traded internationally [86]. The PVD of fuelwood is less than one-fifth the value of sorghum, at ~$0.05/kg. In spatial terms, this limits the distance that trees can be transported, meaning that it is difficult to move them from areas of relative abundance, such as the countryside, to areas of relative scarcity, such as cities. This also helps explain why fuelwood, despite being one of the primary forest products consumed worldwide [87], is rarely traded internationally [88,89]. Inevitably, if the residual market value of smallholders' tree products is negative after subtracting transaction costs, market prices for tree products will have little bearing on smallholders' forestland-use decisions. This is not to say that tree products do not have value in such circumstances but rather that their 'shadow' value is more likely determined by endogenous factors related to a households' internal demand for tree products and the cost of collecting them. This same phenomenon is likely to result in many non-integrated localized markets since producers and consumers in one region cannot cost effectively trade in the other.

The cost of market access becomes an important variable in determining a tree's shadow value when the PVD is too low for there to be multiple buyers that determine a market price at the farm gate. In many cases, the distance between a smallholder's farm and the marketplace can be a better determinant of unobservable shadow prices than the market price received at the point of sale. A useful model for understanding this effect comes from Johan von Thünen's seminal work *The Isolated State*, published in 1826. Von Thünen argued that the value of land is based on location theory and such value is determined by many of the same factors considered by Faustmann such as crop prices, input prices, available technology, agro-ecological conditions, etc., but also considered transport costs as a function of distance [90]. Such distance can be interpreted as cost-adjusted distance to take into account that transportation costs are related to additional factors such as road type and topography.

While this provides theoretical context to why market prices are not always appropriate proxies to the shadow price of tree products, various approaches can be used to estimate value. Contingent valuation methods such as willingness to pay or willingness to accept can be used to estimate the shadow price of tree products [91]. Alternatively, if tree products are only used for self-consumption, their material value can be estimated based on the opportunity cost of substitutes at the margin such as propane instead of firewood (e.g., [92]).

5. Non-Separability and the Endogenous Shadow Prices of Factor Inputs

The shadow prices of factor inputs guide smallholder production and therefore land-use choices. In the absence of transaction costs, exogenously determined market prices guide decision prices. In the presence of large enough transaction costs, the separability assumption no longer holds and the shadow prices for factor inputs become endogenous to a household's preferences and other characteristics of the household and farm. As explained in the sub-sections below, such endogenous elements merit consideration in land-use models and help explain why different households behave differently in seemingly similar contexts. In particular, we discuss how the shadow prices of household-supplied labour, time, land, risk and uncertainty become endogenous variables worth modelling.

5.1. The Endogenous Shadow Price of Labour

Labour is commonly the most important input to smallholder production so its price is a fundamental variable to modelling land-use choices. In the absence of transaction costs, the price of labour is determined by the exogenous and easily observable market wage rate. However, in rural areas of low-income countries that are weakly connected to markets with very seasonal industries, transaction costs prevent the labour market from clearing, so this no longer holds true [93]. In the absence of off-farm employment opportunities, the price of labour is better conceptualized as its opportunity cost when dedicated to on-farm activities. The implication of this is that the opportunity cost of labour at the margin is a function of the productivity of the households' labour, and its work and leisure preferences, both of which are endogenous to the household and not easily observable.

Figure 1 illustrates the effects of preferences and productivity on the opportunity cost of household labour in the presence and absence of labour markets. The horizontal axis represents the total amount of time available within a time period, which can be allocated to any activity, working or not (i.e., leisure activities). When labour markets are frictionless, smallholders supply the quantity Q1 of labour on their own farm. At that point, the marginal returns to labour are equivalent to the wage rate. Given the household's leisure preferences, they continue supplying labour but as a labourer working off-farm at a wage rate. At any point where labour is supplied past point Q3, the marginal utility gained from the wage rate is less than the marginal utility gained from leisure or household activities (e.g., child care). A key implication is that the quantity of labour supplied to the farm and the opportunity cost of labour at the margin are a function of the exogenous market price of labour. However, if off-farm employment is not viable, the household can continue working on their farm past point Q1 but the returns to labour will be lower than the wage rate. The value of the marginal product of that labour becomes a function of the agricultural technology employed on the farm (e.g., fertilizers, crops, planting methods, etc.) and the quality of the labour and the farm. Past point Q2, the utility gained from the returns to labour is below the utility gained from leisure or household activities so they stop working. The quantity of labour supplied to the farm and the opportunity cost of labour are now a function of endogenous household preferences.

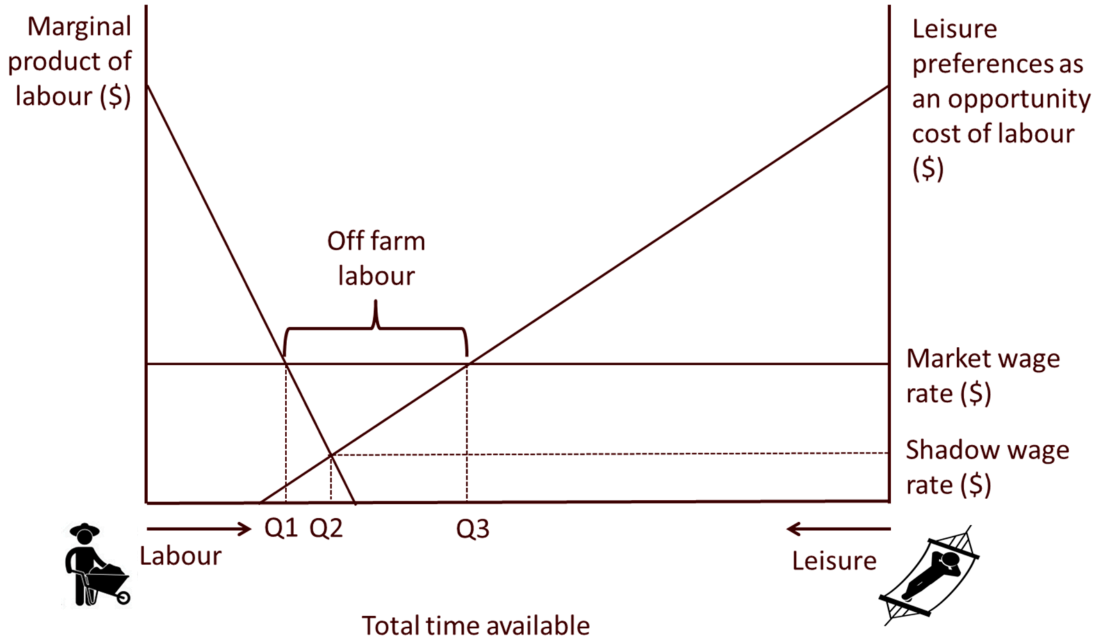

Figure 1. The effects of preferences on the opportunity cost of household labour.

When labour markets are incomplete, an entirely different set of variables become important for determining the opportunity cost of labour, many of which become endogenous to the household. Observable proxies for the productivity of labour are sometimes used such as education or training [94] or it can be estimated directly using a production function [37] or variable profit function [95]. This same opportunity cost of labour can then be used to value various aspects of labour markets such as when smallholders exchange labour days instead of wages. An easily observable alternative proxy for the opportunity cost of time is simply the binary variable of having off-farm employment. It should come as no surprise that the opportunity cost of labour influences forestland-use decisions [96], given that employment increases the opportunity cost of labour and that off-farm employment makes up 9–31% of the rural labour force and accounts for 35–50% of rural household income in developing countries [97]. These relationships likely explain why Godoy et al. [98] and Pichon [99] found a negative relationship between off-farm employment and deforestation, Siren and Parvinen [100] found a negative correlation between employment and the use of non-timber forest products and Warner [101] found that labour availability was attributed to being the primary factor influencing on-farm tree planting decisions.

The price of labour influences agricultural and forestland-use activities differently because of the unique economic profile of trees. Cultivating trees generally requires very little maintenance and infrequent harvests and thus very little labour once the trees are well established compared to most other agricultural crops. However, trees displace land that could be used for other productive purposes. Under such circumstances, one would expect households with a low supply of on-farm labour such as those with off-farm employment, headed by elderly people, and with small family sizes to prefer non-labour intensive activities (i.e., they have a high opportunity cost of labour) such as growing trees even though the revenue per hectare might be low. Harvesting and transporting trees from off-farm sites can also be labour consuming compared to purchasing them from someone else. As such, households with a high opportunity cost of labour are much more likely to buy wood whereas households with a low opportunity cost of labour are more likely to collect it themselves.

5.2. The Endogenous Shadow Price of Time

Time is one of the most important economic parameters related to forest management decisions due to the long delay between planting and harvesting and therefore an integral part of modelling forestland-use decisions. Resources invested into forestry are locked up for a period during which they cannot be used for other productive or consumptive purposes. As a result, inter-temporal trade-offs between present and future consumption need to be considered when forest investment decisions are made. The rate at which such trade-offs are made is known as the discount rate or the rate of time preferences. Individuals with low discount rates show themselves to be more patient and therefore likely to undertake longer-term investments such as growing trees. Individuals with higher discount rates are said to be less patient and therefore more likely to make more short-term investments or require a higher rate of return to invest long term.

According to Fisher's separation theorem [45], the rate of a firm's time preference is represented by the market interest rate (i.e., the opportunity cost of capital) and that a firm's choice of investments is separate from its owner's attitudes towards the investment. However, when capital markets are imperfect, endogenous personal rates of time preferences matter. Atmadja and Sills found that personal discount rates were significant in explaining harvest decisions of limited-resource, non-industrial private forestland owners in India and the USA [17]. Gunatilake, Wickramasinghe, and Abeygunawardena [102] found statistically significant effects between the rates of time preference on the harvesting of non-timber forest products in Sri Lanka, and Godoy et al. [96] estimated the internal rate of time preference of Bolivian farmers living near forests and related it to the rate of forest clearance. When rates of time preferences are independently estimated, they are commonly found to be correlated with socio-economic attributes such as education [102,103], age [17] and wealth [17,103], which in turn are related to forest management behaviour.

Empirical research has also found that rates of time preferences are endogenous to the nature of the investment itself, which is particularly relevant to forestry investments. For example, Frederick, Loewenstein, and O'Donoghue [104] found that time preferences are correlated with the time period in question. While a person might have an implied discount rate of 100% over a one-week time horizon, that same person's discount rate might be 5% over the horizon of a decade. This is particularly important given the longer time periods typical of forestry. Time preferences also vary based on different domains. In other words, the individual rate of time preference is dependent on the good being discounted. Kant [105] argues that an individual's rate of time preference for a particular good depends on the role that the good plays in his or her economic necessities. Hence, an individual may not have the same rate of time preferences for all objects in his or her utility bundle. It makes sense to discount the future value of a timber plantation as originally proposed by Faustmann [41] using the opportunity cost of capital when timber is the only value considered and capital markets are available. However, when trees are grown for a variety of values, the composition of future returns needs to be thought of differently [105]. For example, Meerding [106] found that individuals discounted health at a lower rate than money but that discount rates for environmental values were not different from financial ones. It has also been argued that people may have different personal time preferences and social time preferences based on altruistic or ethical values such as bequest motives. For example, as pointed out by Sumaila and Walters [107], saving for a child's education usually yields a negative financial return and thus a negative discount rate yet it is common practice by people who also engage in behaviours that imply positive discount rates. Voinov and Farley [108] suggest that discounting follows a sort of hierarchy with high, medium and low discount rates for consumptive preferences, the opportunity cost of capital and society, respectively. An example supporting this hypothesis is that Oleson et al. [109] found that indigenous small-scale fishers in Madagascar were willing to give up a sum of money representing nearly 75% of their annual income to bequeath an additional generation with the ability to continue with their cultural identity. Therefore, if growing trees on farms is perceived as a vehicle for bequest to future generations, it is reasonable to believe that discount rates could be lower than market rates of interest.

5.3. The Endogenous Shadow Price of Land

Land is another indispensible factor input for smallholder production that is thought of, and therefore modelled, somewhat differently in the forestry and agriculture economics literature. In the forest economics literature, land is commonly thought of as a capital asset valued at the maximum price that could be paid for it when permanently dedicated to forestry, known as the land's expected value (LEV). The LEV, as previously mentioned in Section 2, is calculated through a deductive process by discounting the future streams of net revenues from timber harvests at the optimal rotation age by the opportunity cost of capital. The objective of calculating the LEV is for decision support when evaluating the merits of alternative silvicultural treatments or estimating the market value of timberland. Its value as a factor of production (i.e., its rental value) can be understood as the opportunity cost of capital when holding forestland assets (i.e., the LEV multiplied by the annual discount rate) [110]. Alternatively, if market price information on comparable forestland is available, the same approach can be used but based on those market values for land as opposed to the LEV. While conceptually parsimonious, measures of the LEV have not been empirically useful at explaining smallholder forestland-use [61–63].

In the smallholder context, growing trees on farms (i.e., farm forestry) is generally conceived as a complimentary activity as opposed to the primary land-use. Smallholder forestry involves the cultivation of trees on farms on either the same unit of land as agriculture or livestock, known as agroforestry or silvopastoralism, or on units of land separate from agriculture but on the same farm. Table 1 below provides a typology of the different types of farm forestry, their contexts in which they commonly occur, their management intensity and common characteristics of the trees. While the types of farm forestry are separated into neat categories for conceptual purposes, they represent a spectrum that transitions between categories. For example, trees along farm boundaries could have occurred naturally without any form of management, and instead be considered as trees on non-arable or fallow land that happen to be placed along a farm boundary. Furthermore, by having trees on farms, there is an increased chance of leveraging positive on-farm interactions and increased benefits for multi-purpose trees (e.g., timber, firewood, forage, fertilization, trellises, etc.). Consequently, simply focusing on timber value per unit of land does not effectively portray the shadow price of land.

Table 1. Typology of farm forestry.

Types of Farm Forestry	Contexts When Likely to Occur	Management Intensity	Common Tree Characteristics
Trees on non-arable or fallow land	In extensive farming and grazing systems, low quality soil, steep slopes, etc.	Low to none. Usually naturally regenerated trees	Low value and quality trees with generally low productivity
Trees in homestead areas	With high valued trees when protecting them from livestock, theft and fires is difficult	High and ongoing. Usually planted and continuously managed	Small quantity of high valued trees such as fruit trees
Trees along farm boundaries	To demarcate boundaries or when trees serve as protective purposes (e.g., windbreak, soil protection, etc.)	Varied. From next to none to intensive management	Commonly nitrogen fixing or forage species. Lateral light encourages bifurcation, which is not ideal for timber production unless the trees are intensively pruned.
Trees inter-cropped on arable land (i.e., agroforestry)	When trees provide benefits to agricultural systems (e.g., through fertilization, soil improvement, etc.	Varied. From negligible to intensive management	Commonly integrated into agricultural management. Trees are primarily used to maintain agricultural productivity.
Trees as the primary land-use on arable land (i.e., farm woodlots)	Generally associated with producing cash crops such as timber, poles, pulpwood, fruits or nuts, etc.	High initially then low after canopy closure	Plantation establishment and maintenance is costly in terms of labour and land assets required.

Adapted from [111].

In the agricultural-household literature designed for the smallholder context of competing land-uses and limited access to capital, land is commonly thought of more as a variable factor of production as opposed to a fixed capital asset. It is commonly valued through an inductive process of empirical estimation as a unit increase in the value obtained from on-farm production from a unit increase of land, known as its marginal revenue product (MRP) [112–114]. Through this conceptualization, smallholders decide how much land to dedicate to different land-uses, one of which could be forestry. When trees are cultivated on parts of the farm that are not suitable for agriculture, the land's opportunity cost can be close to zero. Alternatively, if those same parts of land are complimentary to the farm's overall productivity such as temporarily lying fallow, it could make more sense to measure the MRP at the entire farm-level. This conceptualization is more suitable for modelling smallholders' forestland-use decisions.

5.4. The Endogenous Shadow Price of Risk

The element of risk plays an important role in smallholders' land-use decisions and is therefore important to land-use models. Unlike profit maximizing firms that base their decisions on expected values (i.e., long-run average value of a random process), households are highly influenced by the variance (i.e., risk) of the expected outcome. Research has shown that people in general exhibit a strong asymmetry in their emotional response between gains and losses, so people are not indifferent between alternative payoffs of equivalent expected values. This is particularly true for smallholders since their livelihoods are characterized by unusually high levels of environmental, agricultural, epidemiological, and market risk. Insurance markets are designed specifically to mitigate the effects of such risk but smallholder agriculture is notoriously under-insured. As a result, smallholders tend to exhibit strong preferences towards risk aversion when making agricultural investments and production decisions [115,116]. This implies that households prefer undertaking safe land-use activities with lower expected outcomes compared to riskier alternatives with higher expected values. Such risk preferences have been empirically shown to affect land-use choices of traditional agricultural crops in low-income countries [117], newly introduced crops [118,119], improved farmland management practices [120] and the harvest of timber [121].

In the absence of insurance markets, empirical research has found that measures of risk preferences play an important role in shaping smallholders' land-use decisions, which in turn are shaped by endogenous characteristics of the household, farm, and the investment itself. Gender effects risk preferences in many cultures with women commonly having higher levels of risk aversion than men [116,122]. Human capital affects households' abilities to manage risk and is measured through different proxies such as education and access to extension services. More education is associated with an increase in risk preferences [116]. Access to extension services has the same effect [120]. Age has the opposite effect with older households exhibiting a greater degree of risk aversion [116,120,122]. Household size, which is usually interpreted as a measure of labour supply or income diversification, is also correlated with an increase in risk preferences [119]. The size of the expected payoff has also been shown to reduce risk preferences; higher expected payoffs from an investment are associated with lower risk preferences [122,123]. Measures of wealth are also commonly statistically significant but it is not always clear how this affects risk preferences. Some argue that wealthier households are more capable of taking on risk and therefore have greater risk preferences at the margin [124]. Others argue the opposite; wealthier households have more to loose and are therefore unwilling to take on more risk [115]. Land size for example, possibly a proxy for wealth, has been shown to be positively correlated with risk preferences [122,125] and negatively in others [120]. The dependency ratio, the number of working household members relative to the number of dependents, generally has a negative correlation [122]. Finally, risk preferences can be shaped by smallholders' access and ability to use traditional insurance mechanisms such as labour or output sharing in the event of disaster such as illness. The existence of such traditional insurance mechanisms can affect risk preferences and is sometimes reflected by measures of social capital. Social capital is sometimes hypothesized to play the role of an informal insurance policy but measuring social capital is difficult [116,120]. Measures of social capital are generally measured through proxy variables, meaning that the interpretation of the results can be difficult. For example, some authors in this regard have used the size of the extended family, connections to local authorities, and norms for helping others [116,120].

Growing trees on farms can reduce a households' overall exposure to risk in a number of ways. First, growing trees, like any other additional crop, diversifies the household's production portfolio. This allows them to reduce risk for a certain level of expected returns. If prices for one crop collapse or if pests destroy it, the household can still count on the revenues from their other land-uses. Second, trees are much more resistant to extreme weather events compared to most agricultural crops. This is particularly important since weather shocks are usually systemic to the entire farm. For example, a bad drought that destroys a bean crop is also likely to destroy a maize crop and reduce milk production. However, the same shocks have a much weaker positive correlation with trees that are much more likely to survive. Many of the non-timber values of trees (e.g., spiritual value, shade, etc.) are even less correlated with weather conditions. Third, growing trees on farms presents a store of value that can act as an insurance policy. Unlike most agricultural crops, the timing of forest harvest is flexible. Therefore, for smallholder farmers that do not have access to savings accounts or credit, trees can play the role of a bank, storing value for times when it is most needed [1]. Finally, trees interact with other agricultural crops on farms that can lead to positive outcomes. For example, trees might retain needed humidity for other crops during drought or reduce heat stress, thus increasing the yield of other crops.

Growing trees on farms can also increase a households' overall exposure to risk in a number of ways. First, non-staple-food cash crops such as timber involve a double price risk [126]. When growing food crops entirely for self-consumption, there is no price risk since households consume their own production. When growing cash crops that are not consumed by the household, the first price risk takes place due to the possibility of its market price dropping at the time of sale. The second price risk takes place due to the possibility of the market price of the self-consumption crop rising when it needs to be purchased. Second, the production risk for tree crops is compounded over many years. For example, in any given year, there is the risk that some disaster such as fire or theft will destroy agricultural production. When that happens with agricultural crops, production for that year is lost. When that happens with tree crops, the production of multiple years is lost.

5.5. Uncertainty and the Endogenous Shadow Price of Information

In the absence of perfect information there is uncertainty, which weakens the influence of otherwise important variables in land-use models. While risk implies an unknown outcome from a known distribution, uncertainty implies an unknown distribution of possible outcomes. Such uncertainty is common in forestry due to the infrequent feedback mechanisms between inputs and harvests that sometimes take place at decades or even generational time scales [127]. When a household has been growing the same crop on the same farm over many years, the perception of the actual standard deviation of the production function is likely similar to the actual standard deviation (i.e., expected outcome). Contrarily, when a household is growing a crop for the first time, they do not have past experiences on which to base expectations. Consequently, there is a gap between the expected utility from growing a crop and the perceived expected utility from growing a crop, sometimes referred to as subjective uncertainty [125]. Even if growing trees will increase the land's expected value, they will not be planted unless that is believed to be the case. According to Schults [128], new technologies result in a period of disequilibrium behaviour where resources are not utilized efficiently due to high levels of uncertainty.

Uncertainty can be reduced through the acquisition of new information through various forms of endogenous learning, which can be integrated into models. Perhaps the most common type of learning takes place through experience, an iterative process of trial and error where inputs (e.g., materials and processes) lead to outcomes (e.g., yield, price) that serve as feedback to improve the next round of inputs. This relates both to learning about production methods and market transactions. Learning also takes place by observing the experiences of others. As some farmers within the community adopt new practices, non-adopters observe their outcomes, which increases the state of knowledge [129]. If the results of their neighbours are positive, they are much more likely to participate in the next time period. After each iteration of outcomes, knowledge is gained and the perceived outcomes approach the expected outcomes. Another common type of learning takes place through training, commonly through the form of extension agents, farmer field schools or demonstration sites. Such training can facilitate technology transfer while at the same time relay information back to policy makers to ensure that innovations meet local needs [130]. For example, the creation of demonstration sites of forest plantations by a pulp and paper corporation is viewed to have generated the spread of smallholder tree farming throughout the Philippines [131]. There is a growing literature on how information is shared through social networks where farmers learn about the profitability of a technology and how to use it from the experience of their peers [120,132]. How well an individual is connected within a network also influences the type and speed of information received.

6. Conclusions

In this study, we presented a theoretical construct for modelling the complex decision-making context of smallholders' forestland-use decisions, intended to serve in the guidance and operationalization of future models for quantitative analysis. From within the field of forest economics, it integrates more economic principles to support Herbogn's [133] conclusion that smallholders have multiple forestry objectives encompassing a range of social, environmental and economic values. Our construct combines core economic elements from the fields of forest and agricultural economics concerned with land-use decisions in the presence of transaction costs, and highlights commonalities and differences between the two fields. In contrast to traditional land-use models that are based on maximizing profits subject to exogenously determined market prices, transaction costs create a wedge between market prices and decision prices, thus challenging the separability assumptions. Decision prices of household-supplied and -produced factor inputs and outputs are no longer equivalent to exogenously determined market prices. Decision prices are shaped by endogenous characteristics of the household, farm and landscape.

The key elements to our theoretical construct are summarized as follows. First, smallholders' land-use choices are guided by an objective function based on the utility received from the market and non-market values produced from leisure, agricultural, and forestry land-use activities, subject to their unique set of endowments and preferences. Second, the production function for the tree-based component of the farm is defined by the joint production of market and non-market values and that, in many instances, trees grow in semi-open access areas and regenerate naturally throughout the farm and landscape without the need for variable costs. Consequently, a variety of approaches can be used to model production, which includes the production of factor outputs, the production of factor inputs, and the inverse of the agricultural production function. Third, wood products tend to have a particularly low value density that greatly reduces the distance that they can be transported cost-effectively. As such, spatial characteristics of individual farms and landscapes influence the decision prices of wood products. Finally, smallholders' unique set of preferences, as opposed to simply market prices, plays an important role on the shadow prices for household-supplied labour, time, land, risk, and uncertainty.

It could be argued that the principles discussed in this paper simply need to be integrated as shadow prices (e.g., for the wage rate, the discount, non-market values, etc.) as opposed to market prices in industrial models, and that the word "profit" simply needs to be replaced with the word "utility". The traditional forest economics land expected value model is a highly generalizable representation of how forestland-use decisions are made but it was never intended to account for the multitudes of diverging complexities that arise in real-world economic decisions, especially for smallholders. The land's expected value model is parsimonious as opposed to all encompassing. While this is inherently true, it obfuscates a better conceptualization and thus the appropriate selection of variables required to appropriately analyze smallholders' forestland-use decisions. Rather than trying to force a square peg through a round hole, our theoretical construct offers an improved alternative to guide future research designed to address research questions related to smallholders' forestland-use decisions. We are aware that if a model were built using the many endogenous attributes presented in this article, it would be far too complex to be useful. For this reason, we do not prescribe specific measureable variables to be used to predict or explain forestland-use decisions. Rather, our proposed construct is intended to provide a theoretical basis to assist modellers in the selection of variables for quantitative analysis.

Finally, we would like to end on a precautionary note. We have argued in this article that endogenous preferences fundamentally shape the shadow values of factor inputs and outputs and therefore play an important role in smallholders' forestland-use decisions. Furthermore, we have discussed how characteristics of the household, farm and landscape are commonly correlated with such preferences, providing a priori theoretical notions for the use of appropriate proxy variables. However, many of the same characteristics are correlated with many different types of preferences that risk being confounded with other explanatory variables that are omitted from the model, which are correlated with the same proxy variable and thus biasing the interpretation of the results [134]. Consequently, we encourage researchers interested in modelling smallholders' forestland-use decisions to take great caution when using and interpreting the meaning of household, farm and landscape characteristics. As an alternative, such characteristics can always be used to model shadow prices in a first step and then used to model land-use decisions in a second step.

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