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Analyzing the drivers of tree planting in Yunnan, China, with Bayesian networks

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ABSTRACT

Strict enforcement of forest protection and massive afforestation campaigns have contributed to a significant increase in China's forest cover during the last 20 years. At the same time, demographic changes in rural areas due to changes in reproduction patterns and the emigration of younger population segments have affected land-use strategies. We identified proximate causes and underlying drivers that influence the decisions of farm households to plant trees on former cropland with Bayesian networks (BNs). BNs allow the incorporation of causal relationships in data analysis and can combine qualitative stakeholder knowledge with quantitative data. We defined the structure of the network with expert knowledge and in-depth discussions with land users. The network was calibrated and validated with data from a survey of 509 rural households in two upland areas of Yunnan Province in Southwest China. The results substantiate the influence of land endowments, labor availability and forest policies for switching from cropland to tree planting. State forest policies have constituted the main underlying driver to the forest transition in the past, but private afforestation activities increasingly dominate the expansion of tree cover. Farmers plant trees on private incentives mainly to cash in on the improved economic opportunities provided by tree crops, but tree planting also constitutes an important strategy to adjust to growing labor scarcities.

Introduction

The change from net deforestation to net reforestation is known as the forest transition (Mather, 1992). This aggregate change may result from a cascading set of processes. For example, industrialization might pull people from rural to urban areas leading to a decline in the rural labor force. Consequently, resulting rural labor shortages may spur land-use changes as marginal agricultural land is left uncultivated, possibly leading to forest regeneration (Rudel et al., 2005). Prior research into forest transitions has highlighted the diversity of contexts that exhibit significant forest return, either through natural regeneration or active afforestation (Lambin and Meyfroidt, 2010). The ecological significance of such "regreening" may be highly variable, as the regenerated forest may differ in species composition or quality from the original forest cover (Xu, 2011).

The pathways framework (Lambin and Meyfroidt, 2010; Rudel et al., 2005) is one conceptual approach used to understand the relative role of socioeconomic dynamics and socioecological feedbacks leading to forest transitions. When changes in off-farm opportunities, such as employment in urban areas, are the primary mechanism underlying land-use changes that lead to forest regrowth, such cases are said to follow an "economic development pathway". On the other hand, when land-use change in rural areas corresponds with a shift away from labor-intensive toward capital-intensive agricultural production, such as the cultivation of tree products, a "smallholder intensification pathway" is at work (Rudel, 2009). When observed negative environmental impacts from past degradation lead to policies encouraging forest recovery, the "forest scarcity pathway" is said to be dominant (Hyde et al., 1996). The various pathways to forest transition are not expected to be mutually exclusive, but nevertheless, these ideas are most often used to emphasize the most salient set of drivers in a given case, in order to make comparisons across cases (Lambin et al., 2003; Lambin and Meyfroidt, 2010; Rudel et al., 2005).

We argue that existing forest transition pathway frameworks to date are not sufficiently flexible to understand how forest

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transitions evolve over time and space. A study of forest change in Yunnan Province, China, is used to demonstrate two key findings that we feel have broader relevance to other contexts. First, though particular processes, such as off-farm employment opportunities, may be the most important initial catalysts of change, rural systems will likely continue to evolve over time, and long-term implications for forests will vary according to such ongoing change. Secondly, rural households may be differentially positioned to take advantage of new economic opportunities. For example, household age structure, population growth rates or dependence on forest products could vary at both a household and community level, and the ability to initiate and sustain forest protection efforts will depend on such differences.

We examine recent afforestation programs in China and their specific effects within 17 villages in Yunnan Province. We focus specifically on households as major actors of rural change who to date have received less conceptual and empirical attention in studies of forest change in China. Decades of prior deforestation in China led to severe floods and major droughts, triggering the introduction of large-scale forest programs. We focus here on the impacts of the Sloping Land Conversion Program (SLCP) implemented in 1999. The SLCP encouraged afforestation through the conversion of steeply sloped land to forest or grassland with monetary or in-kind compensation. In addition to new national policies, many regional programs also encouraged farmers to plant trees, implemented by local governments often with support from private companies (Bennett, 2008; Yin and Yin, 2010). Thus, both the SLCP and regional programs have led to increased tree planting on cropland, with multiple local social and environmental impacts (Ediger and Chen, 2006). Evidence suggests that household engagement with tree planting has been highly variable. Greater knowledge of which factors have been most important in shaping land-use adaptations that result in tree planting is necessary to understand the longer-term social and environmental effects of Chinese forest policy. Yunnan is particularly interesting for a study of the relative contribution of forest policies versus the reactions of land users to changing external conditions (Barbier et al., 2010). The province still has abundant forest resources, an ethnically diverse population and is intersected by two globally valuable biodiversity hotspots (Conservation International, 2007).

In order to understand how multiple processes interact over space and time, we employ a distinct methodological approach. Prior analyses of forest transitions that have relied on regression analysis have been limited in their ability to detect causality among multiple, related factors. Other statistical techniques that allow for causal inference in non-experimental settings, such as structural equation modeling, Bayesian analysis and matching techniques have been increasingly used in applied land-change analysis (Alix-Garcia et al., 2012; Andam et al., 2008; Arhonditsis et al., 2006). In this paper, we use Bayesian networks (BNs) to analyze the decision to plant trees on former cropland at the household level. BNs are particularly suited to analyze decision-making in land use because they allow the inclusion of causal and hierarchical dependencies. This includes interactions between variables, accounting for nonlinearity in relationships and permitting the integration of stakeholders in model building and validation (Sun and Müller, 2013). We populate the networks with qualitative information attained from expert interviews and village-level group discussions and with data from a large household survey.

We are interested in how much of the increase in tree cover on former cropland can be attributed to government policies, and to what extent the voluntary tree planting by farmers, with little government support, is responsible. We focus on the household level where land-use decisions are made and analyze the factors that stimulate or hamper the change in household-level land use from cropland to trees. Our overall research questions are twofold:

(1) What are the main drivers that influence the *decision* of farmers to plant trees on former cropland?
(2) Which drivers are the most influential in explaining the *area* planted with trees?

We hypothesize that returns to rural land use are rapidly changing in response to changing economic conditions, which increasingly influence household-level decisions and result in more tree planting on former cropland. We formally assess the relative effects of household labor constraints due to emigration versus the importance of state afforestation programs on tree planting decisions. In addition, private tree planting efforts, outside of formal policies, also represent a rational response to changes in economic conditions. A better understanding of the main drivers of the decision to plant trees and the main drivers influencing the area of tree planting helps improve our knowledge of the distinct forest transition pathways at work in Yunnan.

Forest transition in China

The falling and rising of each Chinese dynasty was always accompanied with environmental change, particularly deforestation and forest recovery. Based on China's long recorded history, China has few, if any, 'pristine' forests. Chinese forests are human-manipulated ecosystems, which have been cut, used, managed and regenerated over time again and again. The latest round of deforestation occurred during the Great Leap Forward from 1958 to 1961 and the Cultural Revolution from 1966 to 1976 (Song and Zhang, 2010; Zhang, 2000). The first forest protection efforts were implemented by the government in the 1980s when forest-use rights were devolved to local communities via the "Three Fixes Policy", which aimed to increase private sector participation by transferring responsibility and benefits of forest management to rural households (Xu and Jiang, 2009). As a result, deforestation rates slowed down and China experienced a change from net deforestation to net reforestation. According to data from national forest inventories, conducted every 5 years in China, forest cover was at a low point of 12% in 1981 (Song and Zhang, 2010). However, the actual transition may have happened later than the data revealed because measurement methods, and even the definition of "forest", were inconsistent across the seven national inventories. For example, in 1994 the definition of "forest" in China was adjusted from a minimum of 30% canopy cover to 20% (Zhang and Song, 2006). Thus, reported forest cover artificially increased in later inventories (Wilson, 2006; Zhang, 2000). In 2010, forest cover in China reached 20.4% according to official statistics (China Statistical Bureau, 2010), and a further increase in forest cover continues to be a policy priority. The goals of the Chinese government aim to achieve a forest cover of 23% in 2020 and 26% in 2050 (SFA, 2009).

Despite the reported rapid increase in forest area, the ecological quality of the Chinese forest transition is questionable. Afforestation efforts were not overly successful in recovering the ecological functions of natural forest cover, resulting in a continuation of soil erosion and flooding (Xu, 2011; Xu and Ribot, 2004). Severe floods and major droughts in the late 1990s triggered the introduction of two vast forest programs: the Natural Forest Protection Program (NFPP) in 1998 and the Sloping Land Conversion Program (SLCP) in 1999. The NFPP aimed to protect and recover natural forests with a logging ban and afforestation schemes (Liu et al., 2008). The SLCP focused on reforestation by encouraging the conversion of cropland on steeply sloped land to forest or grassland with monetary and in-kind compensation (Yin and Yin, 2010). In addition to national