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An empirical analysis of the driving forces of forest cover change in northeast China

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ABSTRACT

In this paper, we investigate the interactions and feedbacks between the drivers of forest cover and other land uses by building a novel longitudinal dataset and adopting alternative modeling strategies. Our longitudinal dataset integrates land-use and land-cover change (LULCC) information, derived by interpreting satellite imagery, with social-economic statistics across eight counties in Heilongjiang over a period of 37 years. Employing both instrument variable and system of equations methods, our models capture the inherent endogeneity embedded in the land-use changes and the effects of such factors as demographic change, economic development, and management transition on the forest condition. To validate the robustness of our models, a series of identification, endogeneity, and other tests are conducted. Our results demonstrate the dominant role of agricultural expansion in forestland loss as well as the importance of considering the substitution between forestland and wetland in analyzing the drivers of LULCC in general and deforestation in particular. The significant coefficient of the Natural Forest Protection Program implies that it has played a positive role in protecting local forests. The positive coefficient of built-up area in the farmland equation suggests a strong link between farming and residential/commercial construction; likewise, the negative coefficient of irrigation indicates that wetland loss is adversely affected by the change in local cropping pattern. It is hoped that these and other findings will improve our knowledge of the forest dynamics and their socioecological drivers, leading to more effective policy making and implementation and, ultimately, better resource conditions.

1. Introduction

China's forest sector has undergone tremendous changes since the mid-twentieth century (Yin, 1998; Yin et al., 2003; Zhang, 2001). In the northeast, the growth of logging and forest products manufacturing and the expansion of farming and local economy, among other things, depleted a vast number of natural forests (Xu et al., 2004; Zhang et al., 2000). Yu et al. (2011) reported that about a half of the matured stands there disappeared in less than 20 years (from 1981 to 1998), with the stocking volume falling from 1660 million m^3 to 860 million m^3. Within the region, Heilongjiang, due to its rich endowment of natural forests, used to be a primary province of timber production in the country (SFA, 2005; Yu et al., 2011). However, it suffered heavy deforestation and forest degradation (MOF, 1997). Jiang et al. (2014) showed that its proportion of mature timber stock decreased from 65.6% in 1984 to only 3.2% in 2004. These problems caused serious soil erosion, water shortages, and habitat losses (Jiang et al., 2014; Xu et al., 2005; Yin and Yin, 2010).

At the turn of the 21st century, the central government was compelled to take drastic measures to halt the deforestation and improve its forest conditions (Xu et al., 2004; Zhang et al., 2000). The Natural Forest Protection Program (NFPP) was thus launched in 2000, with an initial investment of 96 billion Yuan[1] in its first phase (until 2010) to ban or substantially reduce commercial logging while conserving nearly 90 million ha of natural forests and to reforest and re-vegetate an additional 8.7 million ha (Shen et al., 2006; Yin and Yin, 2010). The program is now well into its second phase for the period of 2011–2020 with a commitment of another 244 billion Yuan. In addition to banning commercial logging completely, it aims to promote forest management and revitalize local economies (NFPP Management Center, 2011). Hence, it is interesting and important to investigate the determinants of the fate of the forest ecosystems in northeast China, which is what we intend to accomplish in this study.

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[1] $1 US is roughly 6.7 Chinese Yuan as of July 25, 2016.

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There have been studies of the driving forces of forest dynamics in general and the effects of the NFPP in particular. Using Qinhe Forest Bureau in Heilongjiang as a case, Xu et al. (2005) assessed the preliminary economic impacts of the NFPP. They showed that from 1998 to 2001, logging and processing earnings, together with local tax revenues, had declined sharply. Meanwhile, the income of employees in the forest bureau was improved. As this study was done soon after the program was initiated, the data used were insufficient to support a more comprehensive analysis. Zhang et al. (2011), using a repeated cross-sectional dataset of 35 forest farms over three points of time (2000, 2003, and 2006) in northeast China, examined the forest condition changes in terms of new plantation area, area under strict protection, and timber harvest volume. They found that the NFPP had positive effects, assuming that the geographic and socioeconomic characters across all the forest farms would be homogenous.

Later, Huang et al. (2010) relaxed the homogeneity assumption and concluded differently. They formulated three regression equations in a structural model to explore the causes of forest changes in northeast China from 1985 to 2005, claiming that such socioeconomic factors as total population, rural population, and GDP, had each played a substantive role. Moreover, geographic and meteorological indicators, like terrain slope, elevation, and climate conditions, were deemed to be factors influencing the forest condition. While the empirical results are interesting, its analytical framework is problematic because of the lack of a theoretical foundation and the arbitrary selection of variables.

Mullan et al. (2009) analyzed the NFPP impact on local household income and labor decision, employing a difference-in-differences method and two-period survey data (1997 and 2004) from rural communities. Their results suggested that the program had negatively affected the income of timber harvesting; but it had stimulated more off-farm labor supply in the program areas compared to the non-program areas and made a positive impact on household total income. Nonetheless, the data from only two points of time in the early stage of the first phase of the program did not allow the authors to capture its longer-term effect. Another potential issue is that the recall data before initiating the NFPP may not be equally reliable. Jiang et al. (2014) presented an integrated theoretical and empirical analysis of the harvest and investment behavior of state-owned forest enterprises (SOFEs). Using a dataset of 75 SOFEs in northeast China during 1980–2004, they demonstrated that policy measures could have had positive effects on the development of forest resources through changing the managerial behavior. Due to the rigidity of undertaking any significant reform of the employment and social service systems, however, the SOFEs "have had relatively few effects on harvest and investment decisions, and on development of the forest resources."

These and other studies have provided useful background information and interesting case descriptions regarding the NFPP impact and the forest dynamics in northeast China. However, they seem limited in analytic scope and rigor. First, the case studies are largely based on survey statistics often within a short time span. As a result, there has not been a clear and careful characterization of the long-term trajectory of the forest resources, which is essential to fully understand the historical deforestation and forest degradation and the potential recent forest recovery induced by implementing the NFPP. Second, despite the inherent linkages between different land uses, there has been little work that incorporates other land categories into the study of forest dynamics (Jiang et al., 2014; Mullan et al., 2009; Zhang et al., 2011). Further, previous studies have rarely utilized longitudinal data with consecutive observations that integrate both biophysical and socioeconomic information. Consequently, the forest cover changes and factors influencing these changes remain poorly understood. The goal of this paper is to assess the impacts of the NFPP and other factors on the forest condition in a theoretically sound and empirically appropriate manner.

Specifically, we will investigate the interactions and feedbacks between the drivers of changes in forest cover and other land uses by building a novel longitudinal dataset and adopting a multi-step modeling strategy. The longitudinal dataset will assimilate land-use and land-cover change (LULCC) information, which is derived by interpreting satellite imagery, and social-economic statistics across eight counties in Heilongjiang over a period of 37 years. The modeling strategy will tackle the inherent endogeneity embedded in the land-use changes and capture the effects of such factors as demographic change, economic development, and management transition on the forest condition. The intermittent LULCC data will be interpolated to obtain annual observations and matched with existing annual indicators of socioeconomic conditions for each sample county to enable more sophisticated econometric modeling attempts to better understanding the linkages between social-ecological factors and forest dynamics. To validate the robustness of the results, a number of identification, endogeneity, and instrumentation tests will be conducted. It is hoped that, with the empirical data, modeling strategy, and testing procedures used, this study will improve our knowledge of the resource dynamics and environmental consequences and their socioeconomic, policy, and other drivers, which will lead to more effective policy making and implementation and, ultimately, better resource conditions.

The paper is organized as follows. We describe the methods in Section 2 and the data and variable selection in Section 3. Empirical results, as well as the between-model comparisons of these results, are then presented in Section 4. Finally, the implications of analysis of forest dynamics drivers are discussed in Section 5.

2. Theory and methods

Shi et al. (2016) have documented the land use dynamics during 1977–2013. With minor classes being merged, their classification work features four land-use classes—forestland, farmland, built-up, and other land. Their detection results demonstrate that: (1) farmland and forestland were the two predominant classes of the regional land use; (2) forestland suffered an extended, heavy loss before the end of last century and the decline slowed down significantly thereafter; (3) other land (mainly wetland) declined continuously as well; and (4) built-up land increased persistently during the 37 years (see Fig. 1 below for detail). Based on extended conversion matrices, the authors further reveal the following dominant land transition rules: (1) heavy and continuous losses of forestland and wetland were mainly driven by farmland expansion; (2) while forestland experienced the largest loss in absolute terms, wetland suffered the biggest reduction in proportion; and (3) built-up land encroached virtually exclusively on farmland. Fig. 2 below summarizes these major trends of land conversions.

The complex interactions between these land uses suggest that potential endogeneity could have arisen from: (1) simultaneity intrinsic in land-use conversions over time; and (2) possible indirect or spillover effects induced by other land-use changes (Brownstone and Golob, 2002; Semykina and Wooldridge, 2010). So, characterizing endogenous land-use changes becomes not only desirable but also necessary in our analysis of their drivers (Baltagi, 2006; Fingleton and Gallo, 2007; Jöreskog and Sörbom, 1986). Endogeneity usually refers to situations where nonzero correlation exists between the error terms and certain explanatory variables in a regression model (Chenhall and Moers, 2007; Louviere et al., 2005). If certain explanatory variables are not independent but influenced by other variables within the system, they can lead to biased or inconsistent parameter estimates, making reliable inference impossible (Semykina and Wooldridge, 2010).

While endogeneity and the associated potentially biased estimation are well accounted for in econometrics (Angrist and Krueger, 2001; Angrist et al., 1996; Epple, 1987), econometrics has been slow to adopt the idea of endogeneity testing and correction in analyzing the forces driving LULCC (Irwin and Geoghegan, 2001; Lambin et al., 2001; Verburg et al., 2004). Even as of now, it is still rare to find studies linking LULCC to socioeconomic determinants with a careful handling of endogenous variables (Chomitz and Gray, 1996; Herbert and Arild, 2009; Mertens and Lambin, 2000; Pfaff, 1999; Yin and Xiang, 2010).