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More Trees, More Poverty? The Socioeconomic Effects of Tree Plantations in Chile, 2001–2011

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Abstract Tree plantations play a controversial role in many nations' efforts to balance goals for economic development, ecological conservation, and social justice. This paper seeks to contribute to this debate by analyzing the socioeconomic impact of such plantations. We focus our study on Chile, a country that has experienced extraordinary growth of industrial tree plantations. Our analysis draws on a unique dataset with longitudinal observations collected in 180 municipal territories during 2001–2011. Employing panel data regression techniques, we find that growth in plantation area is associated with higher than average rates of poverty during this period.

Keywords Chile · Forestry · Tree plantations · Poverty · Rural development · Forest policy

Introduction

Today, tree plantations for fuelwood, pulp, and timber production constitute an increasingly large share of many countries' total forest cover—most notably in China, Chile, India, and Vietnam (FAO 2010). Globally, the area of tree plantations will continue to expand in response to growing demand for wood products, for the restoration of degraded lands, as well as for carbon sequestration and its potential role in climate change mitigation and adaptation (Bauhus et al. 2009; Lamb 2010, 2014; Alston and Andersson 2011). Timber from tree plantations is estimated to supply more than one-third of global industrial demand currently, and this proportion is projected to increase (Kanninen 2010) whereas timber supplies from natural forests are likely to decline (Warman 2014).

Despite the above trends, the environmental and social issues associated with large-scale plantation developments are both closely connected and controversial, particularly in developing countries where the commercial expansion of tree plantations has mostly occurred only during the last 50 years, while in other contexts such as Europe, these date back to the 1700s (Nabuurs et al. 2014). The expansion of tree plantations in developing countries preceded, for the most part, the introduction of codes of good practice (e.g., FAO 2006) and certification standards for their responsible management.[1] During this period, large-scale tree plantation firms have sometimes taken advantage of poor regulatory schemes as well as cheap land and labor (Szulecka et al. 2014). Partly as a consequence, a strand of academic and civil society opinion holds that 'industrial plantation forestry' cannot meet both environmental and social sustainability goals. An active debate about these and other perspectives is currently ongoing in the literature (e.g., Vihervaara et al. 2012; Paruelo 2012; Püschel-Hoeneisen and Simonetti 2012). In particular, social scientists have raised concerns about land grabs, displacement of local populations, and poor worker conditions (Gerber 2011), while conservationists are concerned about the expansion of so-called 'green

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[1] For example, by the Forest Stewardship Council in 1996; see http://plantations.fsc.org/.

deserts' of monoculture plantations with associated low levels of biodiversity (Bremer and Farley 2010). Some farmer associations also worry about the expansion of industrial tree plantations making agricultural land scarcer and prompting out-migration from rural areas (Rudel 2009; Schirmer 2007). Not surprisingly, private forestry firms, often backed by their national governments, claim that their business generates much-needed export earnings as well as local employment.

Considering the large amount of media attention given to these controversial claims as well as the high stakes for a large number of actors affected by the relationship between forestry firms and society—including national governments, multinational firms, and indigenous movements—it is surprising that there is so little robust evidence on the socioeconomic impacts of tree plantations (but see Ainembabazi and Angelsen 2014). To date, much of the existing evidence in the developing world is based on either non-systematic observations of isolated cases or purely cross-sectional comparisons without considering dynamic changes over time.

This paper seeks to contribute to a more evidence-based assessment of the socioeconomic impacts of tree plantations. We focus on the case of Chile, where, over the last several decades, monocultures of exotic tree species have come to constitute a significant share of the country's forestry estate. We chose to conduct this study in Chile also because much of the country's government-collected data is freely available to the international research community. The goal of our paper is to contribute to a more nuanced understanding of how rural people, in this case in Chile, have been affected by the rapid expansion of monoculture tree plantations.

The paper is structured as follows: the next section provides background on the role of tree plantations in the Chilean economy, some of their perceived effects on society as a whole and includes two contrasting case studies described in detail from Southern Chile. We use the lessons from these case studies to formulate the paper's main hypothesis, which we present in section three. Section four presents the data and analytical methods used, followed by the results ("Results" section), discussion ("Discussion" section), and conclusion ("Conclusion" section).

Industrial Tree Plantations in Chile: Background

Private firms involved in large-scale plantation forestry are the backbone of the economy in South-Central Chile generating over USD 6 billion annually and representing more than 3 % of the national gross domestic product (CONAF 2013). Timber is the country's second largest export commodity after minerals (Grosse 2010). Under what is often referred to as the "Chilean Model," plantations of fast growing species of pine (mostly *Pinus radiata*) and eucalyptus (mostly *Eucalyptus globulus*) have increased in area from 300,000 hectares (ha) in 1974 to approximately 2,700,000 ha in 2013 (del Fierro Salinas and Díaz Gacitúa 2005; Suazo 2013). This extraordinary expansion is largely attributable to Chile's forestry policy and, more specifically, Law Decree 701. This law was passed by the military regime in 1975 and has provided subsidies to large-scale plantation owners to cover up to 75 % of tree plantation establishment costs (Government of Chile 1975). The law also made industrial tree plantations more profitable by privatizing large swaths of public lands and eliminating taxes on both the land and the products coming from these areas (Aylwin 2000; Montalba Navarro et al. 2005).

Industrial tree plantations are concentrated to the south-central part of Chile. According to the maps produced by the Chilean Forest Service, CONAF, more than 80 % of these plantations are found from the region of Bernardo O'Higgins in the North to the Los Lagos region in the South. (CONAF 2014). These plantations are situated on privately owned land, although the legality of the privately held titles has been contested, especially by the Mapuche indigenous tribes. These groups claim that much of the public land that was sold by the national government to the private forestry firms in the 1970s and 1980s was part of their ancestral territory (Aylwin 2002; Cárdenas and Antileo 2006; Toledo Llancaqueo 2007).

The conflicts between Mapuche groups and private forestry firms continue to this day in the form of legal action, civil disobedience and, at times, violent confrontation (Cárdenas and Antileo 2006; CEPAL 2012; Montalba Navarro et al. 2005). Though many forms of protests involve civil disobedience measures like sit-ins, symbolic occupations, marches, and hunger strikes, conflict has occasionally escalated into violent confrontations involving the burning of forests and farm houses as well as destroying forestry firms' property and equipment (Aylwin 2000; Cárdenas and Antileo 2006; Montalba Navarro et al. 2005). The violence against forestry firms is not only due to discontent with the expansion of forestry plantations on contested lands, but is sometimes portrayed to represent a more general dispute between the Mapuche community and the Chilean government (Montalba Navarro et al. 2005).

The positions of the courts and the national government have, for the most part, sided with the interest of the forestry firms. In 2004, the government charged 18 Mapuche leaders who were associated with burned forests and destruction of private property under the country's anti-terrorist law (Montalba Navarro et al. 2005). More recently, however, the national government has made some concessions to claims by Mapuche groups. For instance, the government has tried to control the conflict through establishing the Land and Water Fund and Origins Program, which devolves land and water rights to indigenous communities (Cárdenas and Antileo 2006). The National Indigenous Development Corporation (CONADI in Spanish) has had mixed results; many Mapuche supporters feel the law does not go far enough and is limited by insufficient funding (Frias 2003; Cárdenas and Antileo 2006). It should be noted that tree plantations have not exclusively expanded in historically contested areas. Another source of land for the expansion of tree plantations has been the vast tracts of relatively sparsely populated land on the western slopes of the Andes as well as the land of small-scale subsistence farmers, many of whom have migrated to urban areas and have sold their land to forestry firms.

From an economic perspective, the expansion of tree plantations has nevertheless been a success. It is a profitable business for the private forestry firms and employs an estimated 134,000 people (CONAF 2013). Supporters of private forestry firms boast of the sector's achievements, which include relieving pressure for forest products from primary forests (Gregersen et al. 2011), enhancing soil nutrients, and reducing soil erosion (FAO 2013; Suazo 2013) Supporters also boast of increasing incomes for rural dwellers by offering new sources of local employment (CONAF 2013) and mitigating climate change through carbon sequestration (Gregersen et al. 2011; Pawson et al. 2013). But critics of Chile's forestry policy—and the plantation subsidy program in particular—argue that the expansion of the plantations has come at high environmental and social costs.

A number of case studies published in Chile document how industrial tree plantations in several locations have been associated with diminishing water resources, declining biodiversity, increased use of pesticides, degraded public infrastructure, increased poverty, and rapid depopulation of rural areas (Arnold 2003; del Fierro Salinas and Díaz Gacitúa 2005; Montalba Navarro et al. 2005; Toledo Llancaqueo 2007; Unda et al. 1997). Scholars have observed a close correlation between the areas where tree plantations exist and where poverty is the highest, and infer from this correlation that forestry firms have exacerbated rural poverty rates because when plantations expand, they argue, the conditions and opportunities for economic growth diminish (Montalba Navarro et al. 2005; Unda et al. 1997; van Dam 2006).

Two of the most well-known cases in Chile where negative impacts have been documented are the local governments or *comunas*[2] of Ercilla and Lumaco in Region IX. We summarize the main findings from these case studies, drawing on published case studies by Bárcena and Catrillanca (2012) and Montalba Navarro et al. (2005). These studies characterize the ways in which industrial forestry activities have affected people—who are predominantly of Mapuche descent—in these two locations.[3] These two case studies are similar in their criticism of the expansion of industrial tree plantations: they make the case that this expansion has had a negative effect on Mapuche culture, reducing the availability of surface water during summer months (Montalba Navarro et al. 2005), and causing rural out-migration (Huber et al. 2008; Little et al. 2009). According to Montalba Navarro et al. (2005), tree plantations in this region were often established on land considered to be sacred by the Mapuche people. Because the Mapuche are no longer allowed to access these lands, prayer traditions have been lost. Mapuche people believe that gods live in the native forest, but since it has been replaced by tree plantations, the gods have fled and no longer protect the local communities (Montalba Navarro et al. 2005).

The authors of these studies also blame tree plantations for the increased fresh water scarcity in these communities and point to the enormous quantities of water that both eucalypts and pines require. In both Lumaco and Ercilla, the scarcity has at times been so severe that the *comuna* governments have had to truck in potable water to the local communities. The author of one the case studies also argues that agricultural production has been hurt by the decreases in groundwater availability, increased soil erosion, and pesticide and pollen pollution—problems that are attributed to the expansion of the nearby tree plantations (Montalba Navarro et al. 2005). Anecdotal evidence from these cases further suggests that one of the reasons that rural people are moving to urban areas is the lack of job opportunities in places where these tree plantations are established. A possible reason for dwindling job opportunities in these areas is that modern forestry firms demand mostly high-skilled labor who can operate the high-tech equipment and machinery. Local inhabitants of these rural agricultural communities rarely have the kind of training modern forestry firms require (Unda et al. 1997). Census data indicate that between 1970 and 2002, the population

[2] The term *comuna* is used interchangeably with the term *municipio* in the context of Chilean public administration. *Comunas* are multipurpose local governments whose territories are mutually exclusive with neighboring *comunas*—territories do not overlap with one another spatially. As such, *comunas* are roughly equivalent to county-level governments in the United States.

[3] Both of these communities have relatively large populations of Mapuche people. The community of Ercilla has 46.5 % Mapuche people (Bárcena and Catrillanca 2012). And over 70 % of the people in Lumaco are Mapuche (Montalba Navarro et al. 2005).

of Lumaco decreased from 13,624 to 8698 (−36 %), even though the national population had grown by 64.5 % during that same time (Montalba Navarro et al. 2005). As a consequence of this drop in local population, schools in some rural areas have had to close down, which make it more difficult for those who stay to have access to education and job opportunities (Toledo Llancaqueo 2007). It is unclear, however, whether this migration pattern would have been any different in Lumaco if the forestry firms had not been there in the first place, as rural to urban migration has occurred throughout the Chilean countryside. It also seems important to recognize that urbanization is not inherently a bad outcome for society as a whole because it may produce enhanced opportunities to access jobs and important public goods and services—that is, insertion into Chile's growing and diversifying urban-based service economy.

In other instances, positive impacts of industrial tree plantations have been reported. In the case of *Forestal Minico* in the Aysén Region in Southern Chile, the company has complemented their monoculture industrial plantations with the planting of native tree species that appear to have generated a host of benefits, including jobs and more positive local perceptions about the value of forestry as a viable form of development (FAO 2011). Another apparent benefit stemming from tree plantations is that their products are broadly appreciated by the urban population in Chile. One study suggests that conservation-oriented urban consumers in Chile prefer products coming from industrial plantations rather than natural forests as long as biodiversity-friendly management practices are applied (Püschel-Hoeneisen and Simonetti, 2012). Most recently, a study commissioned by CONAF suggests that in some regions (e.g., Maule), tree plantation expansion is not linked to rising poverty (Nazif 2014).

One of the limitations of the existing literature on the human dimensions of the expansion of tree plantations is that it cannot tell us the extent to which they have contributed to changes in measures of human development in the aggregate. This is because most studies are localized, do not analyze the interactions between tree plantation expansion and socioeconomic outcomes over time, or draw conclusions from largely descriptive data. Not knowing what the overall effect that tree plantations may have on people's economic welfare at a societal scale is a serious shortcoming for forest policy both in Chile and elsewhere where tree plantations are important to the national economy. Here we seek to address this shortcoming by analyzing the extent to which the presence and expansion of tree plantations have affected changes in poverty indicators for a large number of locations across several years. Our analysis is guided by our central hypothesis, developed on the basis of existing case-study evidence.

Hypothesis

Increasing Tree Plantation Area is Associated with Higher than Average Levels of Poverty

The hypothesis explores the possibility that increases in tree plantation area are systematically affecting the rates of poverty so that the greater the expansion of plantations is at the local level, the greater the proportion of people living in poverty (controlling for potentially confounding factors such as historical levels of poverty, local government budgets, geographic location, and total population). We expect this relationship to exist because the evidence from existing empirical work suggests that the investments by forestry firms in tree plantations do not necessarily provide an injection of financial and human capital into the local economy but rather may create a new set of economic, social, and environmental constraints on local communities. Tree plantations require little full-time and year-around labor, so management is not likely to be conducted by someone locally and the water-resource requirements are considerable. For these reasons, we expect that *comunas* that host these tree plantations to be more likely to experience higher levels of poverty as small-scale agriculture faces increased challenges and economic hardship such as less water available for irrigation, and possible contamination of crops from plantation pesticide fumigation. Given the inconclusive evidence from the existing case studies, however, it is entirely possible that the general effect of plantations on poverty is either null or even positive. Only a rigorous empirical examination can provide an answer.

Data and Methods

In order to assess the longer-term socioeconomic impact of monoculture tree plantations in Chile, we use data from a variety of sources. The principal focus of our analysis is municipal-level data that cover a ten-year period between 2001 and 2011, a period during which the rate of tree plantation expansion was very high for the country as a whole. This is also a time period for which annual data on our variables of interest are available for all the 180 local governments in our area of interest. Figure 1 depicts the expansion in area of industrial tree plantations in Chile from the 1950s until the present.

Chile has taken major steps toward creating accessible longitudinal data across its various government departments. The Municipal Information System (SNIM) provides the bulk of the data for our analysis, through which we examine the impact of plantation expansion and its relationship to poverty in 180 municipalities spread across five administrative regions in southern Chile. This is the

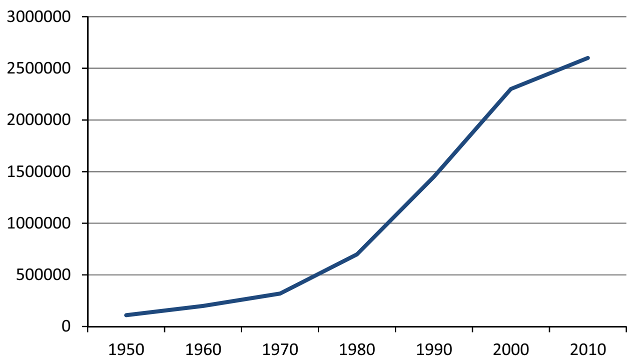

Fig. 1 Area of tree plantations in Chile 1950–2010 (all species in hectares). *Source* Authors' elaboration based on data from CONAF

part of Chile that hosts more than 80 % of the land used of industrial tree plantations (CONAF 2013). Data on poverty and a range of control variables come directly from SNIM, and the data on the area of tree plantations were calculated using information from Chile's 2007 Agricultural Census and yearly planting data from Chile's Forestry Service (CONAF 2013).[4]

In addition to our contemporary longitudinal data, we use a series of variables from historical census data (1965 and 1975; Government of Chile 1965, 1975). We use these data to control for the historical socioeconomic and natural endowments that are associated with local development trajectories in our sample of municipal territories. For example, it seems reasonable to assume that reducing poverty rates in places where poverty is extremely high to begin with will require less effort and fewer interventions than in places where there is hardly any poverty at all. For this reason, we believe it is important that the analysis controls for the influence of historical levels of poverty in the sampled *comunas*. Although there is not sufficient data to construct a complete 50-year longitudinal dataset, we were able to identify two variables that depict historical context of importance to local levels of poverty. More precisely, we compiled historical data on the number of small-holder farmers in 1975 to use as a proxy measure for the historical levels of rural poverty in our sample and to control for historical sources of poverty that may influence the current levels of rural poverty. Another historical variable that we use in our analysis is the number of indigenous land claims in each municipal territory in 1975. Indigenous land claims capture a demographic characteristic that is likely to influence a local territory's development because territories with relatively high proportions of indigenous populations are often more remote and with higher incidence of illiteracy and poverty.

Variables

We operationalize the socioeconomic impact of large-scale monoculture tree plantations by focusing on one particular dependent variable: *comuna*-level poverty. The Ministry of Social Development in Chile collects data on the percent of people in each *comuna* living under the poverty line. In the case of Chile, this means the percentage of local inhabitants who live on less than the equivalent of approximately USD$ 4 per day.[5] For our sample across 10 years, the municipality with the lowest level of poverty is 3 % while the highest is 60 %. The general trend (average) across all municipalities was a steep decline in poverty beginning in 2005 (Fig. 2), which is consistent with the overall trend in Chile as a whole. Less than ten percent of the sampled *comunas* experienced an overall increase in poverty during this period.

We choose to measure the impact of monoculture tree plantations on poverty using the percent of total area in the *comuna* covered by these plantations as our main independent variable. This measure has two advantages. First, the aforementioned theoretical arguments concerning the impact of tree plantations are likely linked to the size of the plantations themselves. Since the size of plantations will be important for generating both potentially positive and negative outcomes, a large size operation will increase the scale of the employment and infrastructure investments, but it will also require more land, fresh water, and pesticide, which may make it harder for small-scale farmers to thrive. Second, it gives a sense of relative spatial size that we argue is important. For example, the socioeconomic impact of a newly established 1000 hectare tree plantation is likely to be greater in a *comuna* with a smaller land surface area than in a larger *comuna*. The average area covered by tree plantations in our sample is 2.1 % of the total area of a municipality, a number that has risen steadily, on average, for our sample during the period under study (Fig. 3).[6]

To enhance the robustness of our models, we include a set of control variables that might also influence poverty dynamics. Although Chilean municipalities have significant decentralized political decision-making autonomy, fiscal power still resides mainly in the central government. There is considerable variation across municipalities when it comes to their reliance on the central government to transfer funds to municipal government coffers. To control for such variability in financial capacity, we include a measure of fiscal dependence, *budget dependence on*

[4] We obtained data on total hectares of forest plantations from the Agricultural Census in 2007 and then used planting data from 2001 to 2011 to calculate the number of total hectares for each year.

[5] The daily estimate is calculated from a monthly income poverty line (Ministerio de Desarrollo Social 2014).

[6] Please note that Figs. 2 and 3 are presented to illustrate general trends in our sample and are not results of our statistical analysis.

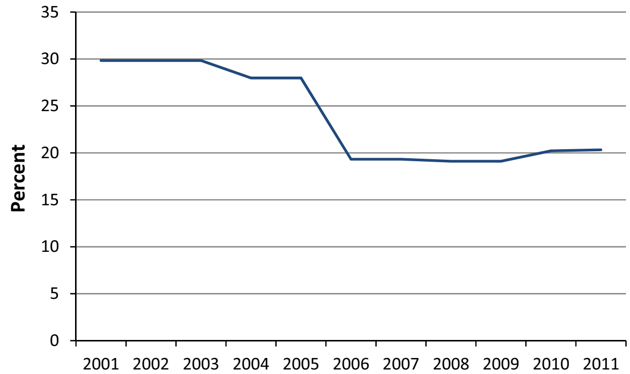

Fig. 2 Average poverty level in sample, 2001–2011. *Source* Authors' elaboration based on data from SINIM

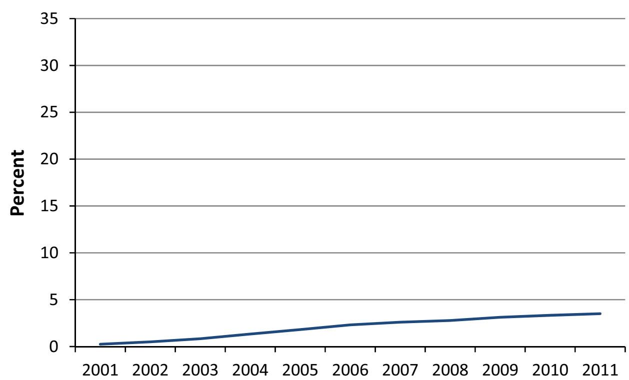

Fig. 3 Average tree plantation coverage (percent municipal land area) in Sample, 2001–2011. *Source* Authors' elaboration based on data from CONAF

common fund. Additionally, we include a measure of *municipal expenditures* to model the varied spending patterns of *comunas* that could also affect poverty rates.

Certain demographic characteristics are likely to be associated with poverty, and we include over-time measures of both the *rural population,* which in this part of Chile has a higher rate of poverty than urban population, as well as measures of *total population.* To account for geographic differences that might affect poverty, we include a measure of barren or *sterile lands* (which, according to the Agricultural Census, is the amount of land that has no vegetative cover) as well as *distance to the regional capital*. Both variables help account for biophysical differences across municipalities that are likely to impact municipal development and subsequently influence poverty. Summary statistics for all variables are provided in the appendix.

We also include in our models historical endowments—both social and natural endowments—that might influence development outcomes. These historical endowments are likely to influence a *comuna*'s ability to reduce poverty and would be important to take into account when testing the socioeconomic impacts of tree plantations. The final set of variables we include are historical variables aimed at controlling for long-term development trends in each municipality. By searching through old, hardcopies of agricultural and population census data, we were able to compile a useful set of historical controls. In a set of models to verify the robustness of our results—explained in detail below—we include measures of *total land area* (1965)*, indigenous land holdings* (1975), and the *number of small farms* (1975). Land area provides a sense of the early resource endowment of a municipality and the other two variables give a sense of land rights and early rural poverty levels and potential for increased economic activity.

Modeling Approach

We elect to use two complementary modeling approaches: fixed and random effects because we are interested in modeling both time-variant (e.g., tree plantation coverage) and time-invariant factors (e.g., distance to regional capital). Although fixed-effects models produce robust results for the time-variant variables, random-effects models are used to study the effects of time-invariant factors. The random-effects model assumes complete exogeneity of the unobserved unit heterogeneity: that no correlation exists between it and the random error or covariates included in the model. As Beck (2004) points out, most random-effects models will violate this assumption. For this very reason, we take a pragmatic approach and compare results from the more conservative fixed-effects estimation with random-effects estimates that can incorporate time-invariant factors.

Equation 1 below describes our baseline fixed-effects model that also includes time fixed effects to account for general time trends, such as generally decreasing poverty rates and the overall trend of expanding tree plantations across the entire landscape under study. Ignoring such overall trends in the data would bias the model output because of temporal autocorrelation. The units of analysis, *comunas* (i), are nested in time (t) and poverty rate (Y) is modeled as a function of time-variant factors (X), unit (municipal)-specific effects (c_i), time fixed effects (δ_t), and unexplained error (ε_{it}). The random-effects model (Eq. 2) includes time-invariant factors (γ), and the first error term (v_i) represents the unobserved unit heterogeneity, between-entity error, while the second (ε_{it}) represents unexplained within-entity error.

$$\begin{aligned}&\text{Fixed Effects Model, Time Fixed Effects}\\&Y_{it} = \alpha + \beta_1 X_{it} + c_i + \delta_t + \varepsilon_{it}\end{aligned} \quad (1)$$

$$\begin{aligned}&\text{Random Effects Model, Time Fixed Effects}\\&Y_{it} = \alpha + \beta_1 X_{it} + \gamma_1 Z_i + \delta_t + v_i + \varepsilon_{it}\end{aligned} \quad (2)$$

Using this basic framework, we conduct our analysis of plantation expansion between 2001 and 2011 estimating the extent to which the relative tree plantation area is

Table 1 Effects of tree plantations on poverty: fixed- and random-effects estimates

Variables	(1) Fixed effects	(2) Random effects
Tree plantations (percent area covered)	0.300*	0.492***
	(0.125)	(0.104)
Budget dependence on common fund	−0.003	0.109***
	(0.028)	(0.022)
Rural population	−0.089**	−0.123***
	(0.032)	(0.023)
Population (thousands)	−0.030	−0.099***
	(0.043)	(0.018)
Municipal expenditures (thousands)	0.001***	0.001***
	(0.000)	(0.000)
Total sterile land		0.051
		(0.069)
Distance to capital		−0.008
		(0.009)
Constant	0.300*	0.492***
	(0.125)	(0.104)
R^2 within	0.515	0.497
R^2 between	0.030	0.320
R^2 total	0.157	0.364
Observations	647	627
Number of municipalities	180	174

Robust standard errors in parentheses (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$). Both models include time fixed effects, coefficient estimates not shown

associated with changes in aggregate municipal-level poverty.[7]

Results

The results of our baseline random-effects and fixed-effects models are presented in Table 1, columns 1 & 2. The initial baseline models suggest that the expansion of industrial tree plantations during this period is significantly associated with higher levels of poverty ($p < 0.05$). The results of the fixed-effects model show that a one-percentage increase (a one unit increase) in the area covered by tree plantations is associated with a 0.3 % increase in the number of people in a *comuna* who live in poverty ($p < 0.05$). The random-effects model shows a substantively similar relationship, although the effect size is slightly larger (0.492, $p < 0.001$).

What do these results mean substantively? One can imagine a *comuna* in southern Chile without existing tree plantations. Over time, a forestry company decides to invest in the establishment of tree plantations so that the proportion of the *comuna's* land that is covered by plantations is one percent. Our models suggest that this expansion is associated with a higher than average level of poverty in the *comuna*'s population compared to *comunas* that did not experience such expansion. Additionally, our results are consistent across the two different panel model specifications (random-effects and fixed-effects models), so we can be more confident that our results are robust and not a statistical artifact.[8]

[7] A more detailed discussion of panel data and model choice is included in the "Appendix" section.

[8] One unique attribute of our data is that poverty at the municipal-level is not measured on an annual basis. Although SINIM reports poverty for each year, the estimates are based on a household survey (CASEN) conducted in 2000, 2003, and 2006 and from population estimates provided by Ministry of Social Development for 2010 and 2011. To address this reporting discrepancy, our baseline models include only four years of data, which most closely correspond with each of the dates of actual poverty measurements or reflect the actual year of estimation. The baseline models therefore include 2001, 2003, 2006, and 2011. However, as robustness checks, we estimate models with poverty data as SINIM reports it, every year from 2001 to 2011, and with interpolated data. We use linear interpolation to generate values for 2001, 2002, 2004, 2005, 2007, 2008, 2009, and 2010. The results are presented in Table 5 in the "Appendix" section. The results of these fixed-effects models are substantively similar to the baseline estimates in both direction and effect size; however, the effect of forest plantation coverage on poverty using interpolated poverty estimates is significant only at the $p < 0.10$ level.

One of the concerns of only looking at more contemporary data related to socioeconomic outcomes is that underlying long-term, historical processes may be at work in shaping current patterns of development outcomes. Our fixed-effects approach addresses this problem by controlling for all time-invariant factors, but it does not tell us substantively what historical characteristics might be important. Development scholars looking at cross-national development often use factor endowments or geography to help uncover longer-term development trajectories or paths (Sokoloff and Engerman 2000). To substantively examine the extent to which historical endowment factors affect the impact of tree plantations, we include three time-invariant factors from the 1965 and 1975 Agricultural Census of Chile. To capture potential geographic characteristics, we include a 1965 estimate of *the total land area* of each *comuna*. We also include a measure of *indigenous land holdings* from 1975 because, as noted above, there are fewer opportunities for economic development in predominantly indigenous *comunas*. Last, we add a measure of the number of small farms to provide a historical control of limited large-scale economic activity. The results of this historical time-invariant model are presented in Table 2.

Although we observe a slight change in the coefficient of tree plantation coverage, the substantive interpretation remains the same: the greater the *comuna*'s relative plantation area, the higher its poverty rate. Indigenous land holding also has a significant effect on poverty: the higher the proportion of indigenous lands, the higher the percentage of people living under the established poverty line. Similar to many societies, indigenous groups, such as the Mapuche in Chile, have struggled to overcome discrimination and marginalization when attempting to access public services. The results suggest that communities with a historically large indigenous presence are still struggling. Interestingly, the number of small farmers in 1975 appears to have a negative and significant effect on poverty ($p < 0.05$). This may reflect the growth and urbanization of certain communities, such as Talca and Rancagua. Half a century ago, they had a heavy concentration of small farmers, but have transformed into important agriculture centers (e.g., vineyards and wine production in Talca) with large populations ($\sim$200,000).

Given the evidence above that tree plantation expansion is associated with a higher level of poverty, it raises questions as to whether human migration patterns within Chile are influenced by this phenomenon and, subsequently, increase poverty at the local level. As noted by several of the case studies discussed in the literature review, plantations may cause rural out-migration. Forest companies may offer farmers or small-land owners cash payments for their land, which, if they choose to sell, forces them to move in search of work. According to these case studies, plantations do not advance socioeconomic development locally and have the negative consequence of pushing poor people out of the rural areas. Another perspective would suggest that water-demanding plantations could exacerbate groundwater shortages, which may add a burden on local farmers, who see farming costs increase and productivity decline. Trapped by structural obstacles, like lack of mobility, these families continue to farm and their income is diminished. In order to test these perspectives more thoroughly, we leverage data on rural population over the past decade and examine the extent to which tree plantation expansion is associated with the size of the rural population. The results of the model are presented in Table 3.

Looking at the relationship between percent area under tree plantations and size of the rural population over the 2000–2011 period, we find that tree plantation expansion is

Table 2 Effect of tree plantation cover on poverty rates: random-effects historical model

Variables	(1) Random effects
Tree plantations (percent area covered)	0.448**
	(0.138)
Budget dependence on common fund	0.055*
	(0.028)
Rural population	−0.114***
	(0.027)
Population (thousands)	−0.079***
	(0.021)
Municipal expenditures (thousands)	0.001***
	(0.000)
Total sterile land	0.073
	(0.072)
Distance to capital	−0.025*
	(0.010)
Indigenous land holdings (1975)	2.378***
	(0.497)
Number of small farms (1975)	−0.009***
	(0.003)
Total land area (1965)	0.000
	(0.000)
Constant	0.448**
	(0.138)
R^2 within	0.496
R^2 between	0.347
R^2 total	0.370
Observations	436
Number of municipalities	122

Robust standard errors in parentheses (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$). Model includes time fixed effects, coefficient estimates not shown

Table 3 Effect of tree plantations on rural population size

Variables	(1) Fixed effects
Tree plantations (percent area covered)	−0.054
	(0.179)
Constant	51.578***
	(0.679)
R^2 within	0.128
R^2 between	0.073
R^2 total	0.001
Observations	1774
Number of municipalities	180

Robust standard errors in parentheses (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$). Model includes time fixed effects, coefficient estimates not shown

not associated with declining local rural populations at a level that is statistically significant, even after controlling for the overall trend in urbanization that is occurring throughout Chile. This does not mean that tree plantations have had no influence over migration. One possibility is that forestry firms see investment opportunities in areas that are already depopulated because the land is cheap and there are few people to displace. However, investigating this question further will require detailed data on migration flows and not just on total population "stocks" for urban and rural areas. Unfortunately, we currently do not have access to such detailed data. Understanding whether tree plantation firms are pushing residents out, or are establishing new plantations in already depopulated areas (because land is available and cheap there) remains an important empirical question for future research.

Discussion

In general, our overall finding that tree plantation expansion is linked to higher levels of poverty stands in stark contrast to a recent CONAF sponsored study (Nazif 2014). Using graphic displays of poverty levels and tree plantation expansion, the authors suggest that in certain regions, the linear trends of increasing tree plantation coverage and declining poverty provide sufficient evidence to establish that more trees mean less poverty. This type of descriptive interpretation of time series trends is often misleading because of the potential spuriousness of a correlation between aggregated variables trending over time, as well as the lack of a counterfactual comparison in the analysis (e.g., poverty in the absence of tree plantation expansion). Without controlling for general time trends of tree plantation area as well as poverty rates, the inferences drawn from such analysis become critically flawed.

Given our main finding that increase in relative tree plantation area is associated with more poverty in Chilean localities, and the absence of a link between plantations and rural out-migration, there remains an important question as to why this might be the case. One potential explanation of the observed relationship is that forestry firms systematically select to invest in relatively poor parts of Chile, so the strategic decision-making process might be driving the results. To investigate whether this is a possible explanation, we analyze the influence of historical socioeconomic factors related to economic development on tree plantation growth. In other words, what factors explain the expansion of monoculture tree plantations across Chilean *comunas* over the past decade? We used a random-effects model to explore the *comuna*-level factors that could influence the investment choices of forestry firms. Results from the random-effects model are presented in Table 4.

The results in Table 4 support the notion that tree plantations establishment is driven by strategic investment decisions but not in ways that change the validity of the observed association between plantation expansion and poverty. We find that localities that have less favorable conditions for economic development are also less likely to be the targets for forestry firm investments. The number of small farmers in a *comuna* (measured in 1997) has a negative effect ($p < 0.10$) on the relative area covered by tree plantations. We also see a pattern with respect to the number of indigenous land holdings, which exerts a negative and significant effect ($p < 0.05$) on relative area of tree plantations. Given prior conflict between forestry firms and indigenous groups over land, the negative relationship between number of indigenous land holdings and tree plantation percent area is not surprising. Firms, both large and small, are now likely to avoid establishing tree plantations in areas with high levels of conflict or social complexity, as this is likely to increase the costs of firms' operations. As a consequence, as suggested by our results, forestry firms appear to be focused on *comunas* with fewer small-scale farmers and indigenous land claims. The potential concern that the choice of where to locate and expand tree plantations would somehow be related to the dependent variable, the poverty level of the *comuna*, does not seem to be supported by these results. Instead, the results suggest that these decisions do not target poorer areas, but rather they target areas that are less dominated by smallholders and indigenous communities. One would have to conclude that there are other mechanisms at work that produce the observed relationship between tree plantation increases and local poverty rates. Existing studies suggest three such mechanisms.

First, tree plantation expansion can come at the expense of agricultural activity, which is often the main source of

Table 4 *Comuna*-level predictors of industrial tree-plantation expansion 2001–2011

Variables	(1) Random effects
Tree plantations 1997 (hectares/1000)	0.000
	(0.000)
Budget dependence on common fund	−0.011
	(0.006)
Rural population (percent)	0.003
	(0.009)
Population (thousands)	−0.006
	(0.005)
Municipal expenditures (thousands)	−0.000
	(0.000)
Total sterile land	0.032
	(0.017)
Distance to capital	0.004
	(0.002)
Number of small farms (1997)	−0.002
	(0.001)
Indigenous land holdings (1997)	−0.093*
	(0.037)
Constant	1.139
	(0.781)
R^2 within	0.443
R^2 between	0.254
R^2 total	0.296
Observations	1735
Number of municipalities	173

Robust standard errors in parentheses (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$). Model includes time fixed effects and region fixed effects, coefficient estimates not shown

income for rural Chileans. With fewer economically active farms in rural areas, the demand for low-skilled labor diminishes. A related possibility is that despite creating a substantial economic boost for the Chilean economy overall, tree plantations may lead to more poverty locally because they offer less economic opportunities to the poorest segments of the local population. Plantations often produce relatively few employment opportunities for locals; and the jobs that do exist often benefit more skilled labor because forestry firms tend to hire mostly semi-skilled workers who are familiar with computer technology and can operate modern machinery (Montalba Navarro et al. 2005). The poorer rural dwellers often lack such skills and can have a hard time getting those jobs. Some studies suggest that while forestry firms generate some employment, the sector is less labor-intensive than agriculture or manufacturing (Torres et al. 2015).

A second possible mechanism is related to how tree plantations affect migration patterns of rural people moving to urban areas (Azócar et al. 2007; Berdegué et al. 2001). In the previous section, we detected no signs of tree plantations affecting the size of the total *comuna* population, but it is possible that rapid tree plantation expansion makes it more likely that the younger rural dwellers migrate to cities. Those that are more economically active migrate to the cities first for education and then staying to work because they find more opportunities to find salaried jobs. According to this logic, it is their parents—who often earn less income—who stay behind in the rural areas and will live off subsistence farming and possibly remittances from their children. A household that experience such a transformation would show up in the national statistics as a household that has become poorer economically and possibly causing the aggregate poverty rate to go up for the *comuna* as a whole.

Finally, several studies have indicated that tree plantations may have a negative effect on the overall conditions for broad-based economic development. Studies emphasize a mix of three factors that have indirect negative consequences for local economic opportunities. Forestry firms use and degrade public roads and other infrastructure without necessarily paying for the wear and tear caused by heavy machinery (Schirmer and Tonts 2003). A second factor is their disproportional use of water resources, which leaves less for local communities to use. Chilean water rights are such that local communities have difficulties claiming water when such claims are at odds with those of private firms, even if communities historically have had non-rivaled access to local water sources (i.e., Bauer 2005). Not having enough water, as exemplified by the case studies from the *comunas* of Ercilla and Lumaco (Montalba Navarro et al. 2005), will make all economic activities and especially agriculture more uncertain and less profitable. Increased pollution, both from excessive application of pesticides and the dust from increased truck traffic on dirt roads in the countryside, can make the local population less productive economically and possibly increase their health care costs.

There are notable exceptions to this general negative effect of tree plantations on the local economy. There are places in Chile where the story is quite different from the observed general pattern. For example, in Los Muermos in Region X, tree plantations seem to have helped, not stymied, economic growth. Los Muermos is covered in 26 % of native forest and has an employment sector that includes agriculture, farming, and forestry (La Municipalidad de Los Muermos 2011; Biblioteca del Congreso Nacional Chile 2012). Los Muermos is at the forefront of adapting to the economic model of tree plantations. Since 2008, the *comuna* took the initiative to get more engaged in governing the forestry operations in its territory. Los Muermos created the Department of Forest Development and organized a series of forestry workshops that brought together a wide variety of stakeholders—including members of government, academia, civil society, and business—to talk about constraints and opportunities in the forestry sector to improve the opportunities for human development in the *comuna*. It is a good example of a local population and its political representatives grappling with the challenges facing its rural residents and the economic potential surrounding forest plantations. The initiative stands in sharp contrast with the responses, or rather the lack thereof, in many of the neighboring *comunas*. The experience in Los Muermos, compared to experiences in neighboring *comunas*, suggests that the socioeconomic impact of tree plantations is not deterministic but will depend to a large extent on the ways in which the local actors interact with, and respond to, the forestry firms.

Conclusion

In this paper, we have sought to contribute to the debate on the human dimension of industrial tree plantation expansion in Chile. Reflecting on the evidence presented in our analyses, we identify three key messages:

First, we find that monoculture tree plantation expansion can exacerbate poverty. Although we do not have data to adequately identify a causal mechanism, we do find that the greater a municipality's relative area under tree plantations, the higher its poverty rate from 2001 to 2011. This relationship is robust to a number of alternative ways of analyzing the data.

Second, we do not find that tree plantation expansion is associated with declining size of rural populations. One commonly held view is that tree plantations in Chile are causing large-scale out-migration from plantation-rich locations. Our results are inconsistent with this perspective in the sense that no statistically discernable relationship is present from 2001 to 2010. Tree plantations may very well cause the displacement of some Chilean families, but the magnitude of the impact (relative to the dramatic rural to urban migration taking place in southern Chile) appears to be minimal.

Third, our qualitative study of Los Muermos suggests that more pro-active local governance responses to tree plantation expansion can alter outcomes. The effect that tree plantation expansion has on the local population seems to be, to some extent, dependent on how the local population and forestry firms chose to engage with one another.

Our analysis also suggests that there are many remaining questions regarding the mechanisms that are at work to create the observed patterns. Our qualitative explanation to these patterns—that forestry investments often place increased burdens on local farmers—would benefit from further theoretical and empirical analyses. One should also note that our analysis is limited to a relatively short period (10 years). And although this is a period during which there has been a high rate of expansion of tree plantations, it only represents a brief window within the forty-year period since Chile's government decided to make industrial tree plantations a national development priority. It is possible that had we had the same data for the first ten years of tree plantation expansion in Chile—say from 1975 to 1985—the results may have been quite different. Future studies should try to leverage historical census data to replicate the analysis conducted here, but for a longer time period.

Given the current and projected future significance of tree plantations in the world economy, the need for systematic evidence on their effects on rural communities and urban users is essential for natural resource policy (Anderson et al. 2013; Williams 2014). To this end, management should implement low-cost monitoring and data collection protocols to gauge future social and environmental impacts. Establishing baseline data on social and environmental impacts will allow researchers to effectively measure changes in future social and environmental impacts and adjust policies and practices. Other Latin American countries such as Ecuador are currently launching ambitious, government-led forest plantation programs aimed at increasing the competitiveness of the forestry sector in the next decades through a generous incentive scheme (MAGAP 2015). Further, the application of existing guidance on the institutional, economic, social, and environmental dimensions of planted forest expansion (FAO 2006) may help to place the ever-growing land-use type into broader development goals at the national level, help to minimize conflict, and promote societal acceptance. All stakeholders, including the private sector, would benefit from having more robust evidence on the socioeconomic effects of tree plantations so that decisions can be informed by more balanced outcome assessments.

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Appendix

Panel Data and Modeling

Panel data structures are usually defined by repeated observations of many units (large N) over a short period of time (<20). This differs from time series cross-sectional

Table 5 Effects of tree plantations on poverty using alternative years and data on poverty (fixed effects)

Variables	(1) SINIM original poverty data	(2) Interpolated poverty data
Tree plantations (percent area covered)	0.421**	0.198
	(0.152)	(0.121)
Budget dependence on common fund	0.018	−0.007
	(0.020)	(0.015)
Rural population	−0.088	−0.035
	(0.045)	(0.033)
Population (thousands)	−0.011	0.007
	(0.058)	(0.043)
Municipal expenditures (thousands)	0.000	0.000
	(0.000)	(0.000)
Constant	32.986***	30.407***
	(2.749)	(2.062)
R^2 within	0.535	0.583
R^2 between	0.095	0.004
R^2 total	0.248	0.121
Observations	1765	1793
Number of municipalities	180	180

Robust standard errors in parentheses (*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$). Model includes time fixed effects, coefficient estimates not shown

data in that the asymptotic properties pertain to N rather than to T. Ignoring the panel structure of the data can be highly consequential statistically (e.g., violations of OLS assumptions that produce bias and inefficiency) and can limit the substantive questions researchers are able to explore. In this particular case, we are interested in the variation in poverty and tree plantations across municipalities in southern Chile, and within each municipality over time. To explore the relationship between tree plantations and poverty, there are two standard econometric approaches: fixed and random effects. The fixed-effects approach models the equivalent of a unique intercept for each unit. In other words, each unit has set of unique characteristics (unobserved) that do not change over time, so any change in the outcome of interest is due to something other than these fixed characteristics. A random-effects model assumes that variation across units (municipalities in this case) is random (as if drawn from a sample) and of substantive interest. Practically speaking, random-effects models allow researchers to estimate the effect of time-invariant characteristics (e.g., historical endowments).

As previously mentioned, deciding which approach to use involves both statistical and substantive considerations. Results from a Hausman test ($p < 0.01$) of our baseline models (Table 1), which assesses if the unobserved heterogeneity assumption of random-effects model holds (conditional on the correct specification of the fixed-effects model), suggest that a fixed-effects specification may be preferable. However, given our theoretical interest in time-invariant characteristics, we take the practical approach of estimating models with both fixed effects and random effects, and find similar estimates regardless of model specification.

See Table 5.

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