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Drivers of forest cover change in Eastern Europe and European Russia, 1985–2012

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ABSTRACT

The relative importance of geography, history, and policy in driving forest cover change at broad scales remains poorly understood. We examine variation in forest cover dynamics over the period 1985–2012 across 19 countries in Eastern Europe and European Russia in order to shed light on the role of these in driving forest cover change after the collapse of socialism. Using a combination of cross-section and panel regression methods, we find that privatization of forest lands increased forest cover loss due to logging, as did increases in agricultural land between 1850 and 1900. Land quality has no power to explain variation in forest loss between countries, nor does trade and price liberalization policy. None of our covariates explain forest regrowth on non-forested land over the period. We conclude that history and land privatization drove important cross-country variation in forest dynamics in the region, but that the majority of forest cover change over the period results from shocks, both political and economic, shared by all countries in the sample. This highlights the importance of broad-scale shocks as drivers of forest change, relative to geographic and policy variability across individual countries.

1. Introduction

The collapse of socialism is perhaps the most substantial natural experiment in social change that has occurred in modern history. It was sudden, resulted in major structural changes, and country-level policy responses were strikingly varied. The collapse also triggered widespread land use changes, including land abandonment, disparate forest cover changes, and the rapid expansion of urban areas resulting from large rural-to-urban migration (Foley et al., 2005; Hostert et al., 2011). However, while the overall shock was shared by all countries in the region, the inherent political, socioeconomic, and institutional differences have created divergent transition paths across countries with subsequent variation in land use change (Lerman et al., 2004a; Prishchepov et al., 2012; Griffiths et al., 2013). Our goal here is to compare the importance of geography, history, and policy in explaining differences in the intensity of forest use and regrowth over the tumultuous post-socialist period. We examine forest loss and gain across Eastern Europe from 1985 to 2012 to understand how policy differences among countries affect these trends. Our specific questions – related to these three subsets of determinants – are:

1 Does trade liberalization explain forest loss or gain? Theory suggests that if countries start off with equally distorted economies, liberalization should lead to greater efficiency in resource use, so that countries with bigger changes in liberalization policies should expect to see larger reallocation of resources, increasing forest loss from logging in locations with comparative advantage of forest production, and decreasing it where comparative advantage is not present.
2 Do key historical events have a persistent effect on land use change today? For forest harvesting, but also for agricultural activities, land use in the distant past may strongly influence current behavior. Given rotational cycles, forest management decisions made around the turn of the 20th century may still be visible in forest loss from logging patterns 100 years later.
3 Does geography "trump" policy and history? Geographic features, including environmental variability such as inherent land productivity, should strongly determine the location of productive activity related to forestry and agriculture. For example,

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countries with more suitable land for agriculture should have less agricultural land abandonment.

Our paper contributes to the broad literature on land use change in transitioning economies. Prior work on post-socialist land use change in the region has generally employed two approaches: papers examining subsets of countries, often focusing on cross-border variation, and those assessing within-country variation. The within-country studies provide important insights into the location of land use change within a relatively uniform institutional environment. Albania, for example, engaged in large scale agricultural land privatization. A combination of village-level survey data and satellite images revealed that drivers of land use change varied significantly during the different stages of transition. Initially, land fragmentation served as a risk diversification strategy for rural households and therefore slowed down abandonment rates (Sikor et al., 2009), so abandonment occurred in remote, less-populated areas. In later stages, land fragmentation lead to greater abandonment (Müller and Munroe, 2008), and variation in land abandonment was strongly correlated with out-migration (Sikor et al., 2009). In Romania, topographical characteristics played a more dominant role in predicting cropland abandonment, and rural population and migration were weaker predictors (Müller et al., 2009). It is difficult, however, to draw broad conclusions regarding the importance of policy variation by examining only within-country variation.

There are a number of studies comparing rates of land use change among subsets of the countries in the region. These studies are useful for understanding how differences in institutional environments across similar ecological zones can affect land use. The complexity of the process is emphasized in narratives detailing land use change across long periods that highlight the importance of both path dependency as well as unexpected change (Jepsen et al., 2015). The region has provided a rich environment for cross-border analysis (Kuemmerle et al., 2008; Hostert et al., 2011; Alix-Garcia et al., 2012; Griffiths et al., 2013). One analysis across the boundary triangle of Poland, Ukraine, and Slovakia revealed the influences of different biophysical factors, land ownership, and other institutional drivers (Kuemmerle et al., 2008). High abandonment rates in Poland and Slovakia were explained by decreasing rural population and the land privatization process (Palang et al., 2006), whereas in Ukraine weak institutions and decreasing government support for agriculture were key explanatory variables (Wegren, 2003; Lerman et al., 2004b). Another approach exploited matching and regression analysis to create comparable control groups based on the same baseline characteristics, and found that biophysical factors were the main forces driving divergent abandonment rates in Poland and Slovakia (Alix-Garcia et al., 2012). A meta-analysis of case studies within the region indicated an important role for socio-economic factors in driving land use change across the Carpathians (Munteanu et al., 2014). However, most of the within-region work is limited to two or three countries. Only one study examined five former Eastern Bloc countries based on a selected set of satellite imagery after the early 1990s (Prishchepov et al., 2012). To eliminate potential confounding factors, which could affect agricultural productivity (such as elevation and slope), that study focused on one area within relatively homogenous agro-ecological conditions but large variation in institutional changes. They attributed higher land abandonment rates in Latvia (42%), Russia (31%), and Lithuania (28%), to delayed institutional change in land privatization and the decline in government support for agriculture.

The advantage of using within-country variation or small subsamples of countries is that fewer factors can potentially confound inference on drivers of land use change. However, within-country variation does not capture the large differences in transition approaches across countries, nor does it allow us to infer the relative importance of policies versus other drivers of land use change at a broad scale. We are aware that cross-country regression analysis, which we will use in this paper, is fraught with problems of inference due to the joint determination of policy and outcome variables (Temple, 1999; Durlauf et al., 2005; Easterly, 2005). However, while these issues are clearly a challenge to our study, we believe that the exercise is justified for three reasons. The first reason is that we use first differences and fixed effects regressions to help eliminate time-invariant unobservables. Second, the endogeneity of policy to land use change is likely less severe than it is for economic growth, since land use outcomes occur over a longer time scale. Finally, we do not interpret our estimates as causal, but seek to understand whether the variation in land use change rates across countries can be explained by variation in a small subset of potential key variables according to the literature, and we carefully examine the correlation among these variables.

2. Methods

2.1. Study area and background

Our study region covers approximately 7.5 million square kilometers and includes 19 Eastern European countries, which we group according to the commonly used categorization of CIS (Commonwealth of Independent States) and CEE (Central and Eastern European countries) (Mathijs and Swinnen, 1998; Lerman et al., 2004a; Rozelle and Swinnen, 2004). The CIS countries are Russia, Belarus, Ukraine, and Moldova,[1] and the CEE countries are Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Macedonia, Montenegro, Poland, Romania, Serbia, Slovakia and Slovenia. The study region spans a wide variety of biomes, ranging from Mediterranean in the South, over temperate grass and scrublands at mid-latitudes, to temperate and boreal forests and finally tundra in the northernmost reaches (Olson et al., 2001). The region also includes lowland areas highly suitable for agriculture, such as most of Ukraine, Poland, Belarus, and Hungary, as well as a variety of forest ecosystems spread across the three major mountain systems – the Urals, the Caucasus and the Carpathians. The countries with the highest percentage of forest cover are Slovenia (62.4% of the land area), Latvia (54.3%) and Estonia (51.8%) and the countries with lowest forest cover are Hungary (22.6%), Ukraine (16.8%) and Moldova (12%) (WDI, 2012).

The collapse of the Soviet Union constitutes the most recent geo-political and socio-economic transition in a region well-versed in transition.[2] In the 19th century, the study region was divided between the Prussian, Habsburg, Ottoman and Russian Empires, with European geo-political borders shifting several times, new countries emerging following the two World Wars, countries changing from monarchies to democracies and totalitarian governments. The collapse of the Soviet Bloc in Eastern Europe and adoption of market economy principles brought about a number of policy changes that had important direct and indirect effects on the agricultural sector. Such policy changes included the removal of state subsidies to output and input prices, which resulted in starkly deteriorating conditions for trade and hence negatively affected agricultural profitability (Rozelle and Swinnen, 2004). Our study focused both on the most recent transition following the collapse of

[1] Note that we include only 4 of the 12 CIS member and associate states. The missing CIS countries are all located either in Central Asia or in the Southern Caucasus, and their environmental and socioeconomic conditions are so different that it be questionable to both group them with the Eastern European CIS countries and compare them to the CEE countries. Given this sample, we cannot extrapolate to all CIS member states.

[2] Riasnovsky and Steinberg (2010) and Bideleux and Jeffries (2007) note that drastic changes in land use and land cover accompanied these shifts.

Table 1
Summary statistics before and after 1995.

	1985–1995	1996–2000	Diff.
Price liberalization index	2.966	3.993	−1.027***
Trade liberalization index	2.544	3.910	−1.366***
Population density (per km2)	81.530	78.886	2.644
Urban population (%)	60.277	61.604	−1.328
Agriculture in GDP (%)	14.367	7.875	6.492**
Industry in GDP (%)	38.197	30.443	7.754***
Service in GDP (%)	47.436	61.682	−14.246***
Labor in agriculture (%)	18.821	15.096	3.725
Labor in industry (%)	35.512	29.538	5.975*
Labor in service (%)	41.142	53.848	−12.707**
Observations	38		

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.
Data sources: Liberalization indices: EBRD (2015); other indicators: World Development Indicators (2012).

socialism as well as the potential legacies resulting from affiliation with land use practices during the Imperial era.

To examine the effect of different policies on forest cover change, we compiled (a) key transition policy indicators, (b) world crop and timber prices, (c) socioeconomic data from various sources, and (d) geophysical variables. This section both describes the sources of these data and provides summary statistics. Before we describe these data sources, we show a few statistics in order to provide context for the economic upheaval that occurred during the study period, even though we do not use many of these covariates in our analysis do to their potential endogeneity.[3] We obtained much of the data presented in this section from the World Bank's World Development Indicators database. Two key transition indicators for price and trade liberalization were taken from the European Bank for Reconstruction and Development (EBRD), and we used these directly in the quantitative analysis. These two variables are scaled from 1 to 4 and reflect the country-specific policy progress in transition from centralized planned economy to free market economic with regards to policies affecting domestic prices, trade and foreign exchange controls after 1989.

To give a sense of the scope of the economic changes, summary statistics (Table 1) show the changes in the means of socioeconomic variables before and after 1995. Over the transition period, liberalization of both prices and trade, as indicated by the EBRD indices, increased significantly. Population density was slightly lower, probably as a result of out-migration and higher death rates rather than changes in fertility (Kontorovich, 2001). Over time, there is significant shrinkage of GDP from agriculture and industry, and increasing dependence on the service sector. Labor allocations, however, do not change commensurately – labor in agriculture is relatively stagnant, and labor in industry decreases, but the decrease is only marginally statistically significant.

There is variation in these changes if we split the countries into CIS and CEE groups (tables available upon request). CIS countries tend to have higher baseline levels of agricultural and industrial GDP than CEE countries, which generally start the study period with higher shares of labor in the service sector. The population density decrease is also larger in CIS countries. Furthermore, liberalization tends to increase more quickly and end up at higher levels in the CEE countries. However, broadly speaking the trends are similar.

[3] Measures related to sectoral GDP growth and employment, for example, are likely to both determine and be determined by forest sector activity as measured by decrease in forest cover. This would mean that a regression coefficient on change in sectoral labor or GDP would be biased in our analysis as a result of reverse causality.

2.2. Data

2.2.1. Forest cover data

We use information on forest cover dynamics per country as the main outcome data in our analyses. This information is difficult to collect from national sources. Changes in country boundaries, reformation of statistical and natural resources agencies, and modification of forest inventory methods render national forest data incomparable across borders. For many countries, this data is also hard or impossible to collect.

In order to maximize comparability across countries, we analyzed satellite data to measure forest extent and change consistently within the entire region from 1985 to 2012 (Potapov et al., 2014). Our analysis was based on the entire archive of Landsat satellite data which is available from the U.S. Geological Survey Earth Resources Observation and Science Data Center. We developed and implemented an automatic system for satellite imagery processing, including cloud screening, reflectance data normalization, and multi-temporal compositing. In total, we processed nearly 60 thousand Landsat images collected over 27 years, each image covering 31,000 km^2, with pixel size of 0.1 hectare. Data processing is described in detail in Potapov et al. (2014). The image composite time-series served as the source data for forest cover extent mapping, and for detecting changes in forest cover, recorded as gross forest cover loss (which includes any forest clearing as result of forest harvesting, infrastructure development, or natural disturbance), forest loss due to forest harvesting versus natural disturbances, and gross forest cover gain (forest recovery after disturbance, or new forest establishment over previously non-forest lands).

Forest cover and change characterization employed a supervised statistical learning tool (decision and regression trees (Breiman et al., 1984)) and was guided by expert-derived training data. The forest cover extent mapped with Landsat data was closely comparable with official national (FAO, 2010) and regional (ROSLESINGFORG, 2003) statistics for year 2000, with the difference between official and remotely-sensed area estimates within 10% at individual country (region) level. We validated forest cover change results following "good practices" recommendations (Olofsson et al., 2014) and found that all products except abandoned cropland afforestation have high accuracy, with sample-based and map-based area estimation in agreement within +/−7%. It should be noted, however, that Landsat-based data were not suitable for mapping selective logging and partial tree mortality, and only represent areas of stand-level disturbance. Mapping forest establishment over non-forest cropland and pasture areas of 1985 was the most complicated part of the satellite data analysis, because forest encroachment over abandoned agriculture lands is a slow process limited by distance to seed sources, high frequency of fires, and a dense sod layer prohibiting seedling establishment. As a result, only areas where dense forest cover was established by 2012 were mapped as forest gain, and, according to sample-based validation results, afforestation over abandoned agriculture lands was underestimated by 21% (Potapov et al., 2014).

The results from the satellite image analysis include consistent data of forest cover extent for 1985, 2000, and 2012; annual gross forest cover loss from 1985 to 2012; and decadal gross forest cover gain. Overall, the following variables derived from the regional-wide data (and separated by country) we use for the analyses: (i) forest loss from logging; (ii) forest cover gain over previously non-forested land (which we call agricultural abandonment); (iii) forest loss from logging over five year time steps. The dataset measures 216 million hectares of forest in 1985, and 226 million in 2012. There is a total forest loss from logging over this period of a little over 22 million hectares, and gain on previously non-forested land of around 3.8 million hectares. However, there is also substantial forest recovery in areas where forests were previously lost. In other words, given the nature of land cover classifications, there are at any point substantial areas that were recently disturbed, and hence are not forest (in terms of land cover), but they are not agriculture either. Because loss and gain can take place repeatedly over such a long time period, and because we exclude here loss from fire and wind, one cannot simply sum the gain and subtract the loss to 1986 in order to find forest area in 2012. Further discussion of these dynamics in the data that we use in this paper can be found in Potapov et al. (2014). The means of forest loss from logging and gain on non-forested land over the time period of interest can be found in Table B3.

These variables show substantial variations among countries (Fig. 1). Net forest cover increase occurred in all countries, except Estonia and Latvia. The highest forest loss from logging occurred in the Baltic states: Latvia, Lithuania, Estonia. Forest loss from logging was also very high in Hungary and the Czech Republic, but this should be interpreted in the context of their relatively low levels of forest prior to the transition. The forest loss from logging during 2001–2010 interval was much higher compared to 1985–1988, and there is substantial clustering across space. In general, there is a northern (Baltic State), a central (Poland, Belarus, and the Czech Republic) and a south-western clusters of countries with similar deforestation rates in most periods. The question arises: what

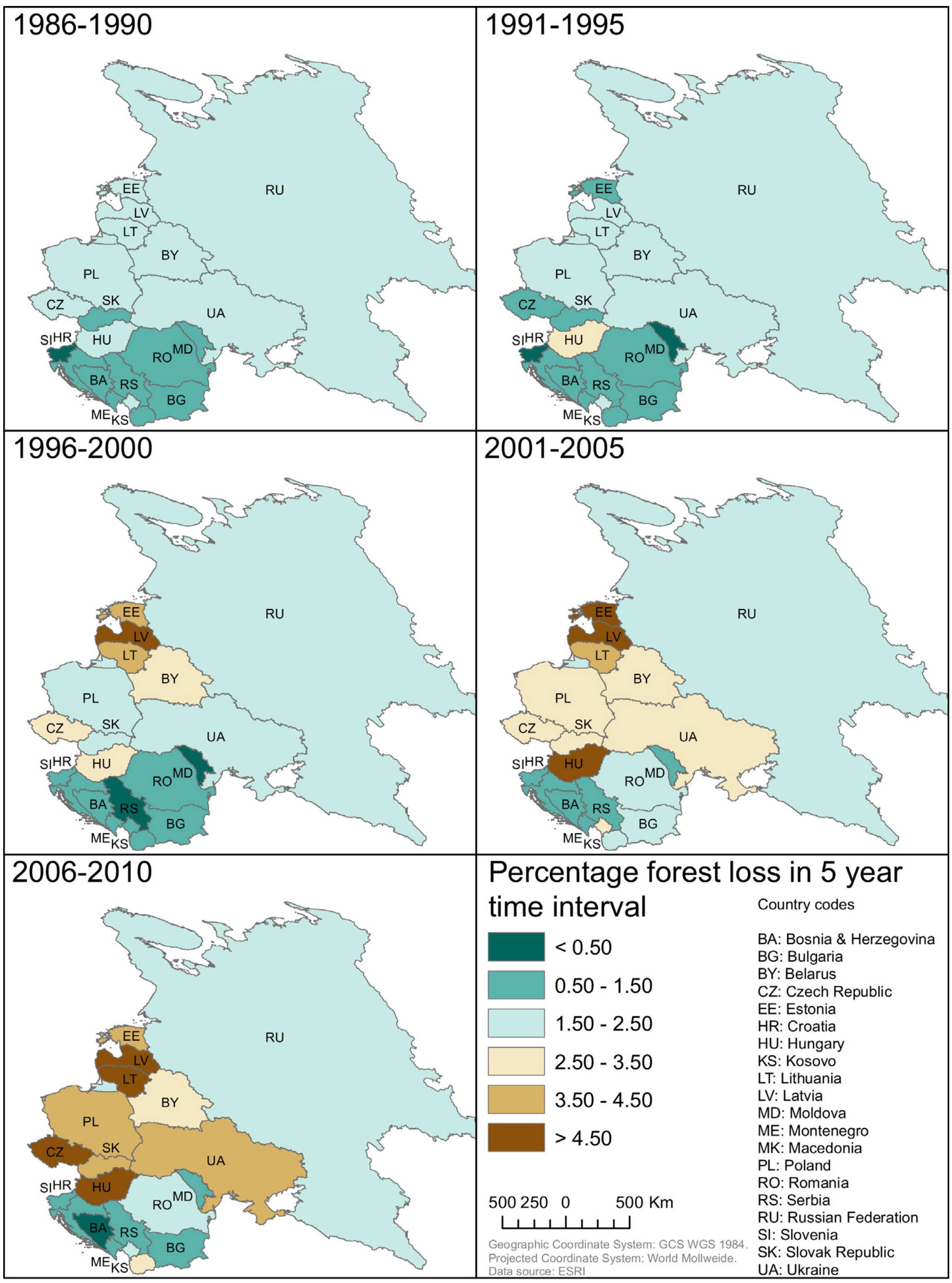


Fig. 1. Forest loss from logging in five year intervals, 1986–2010. *Data source*: Potapov et al. (2014).

might explain these differences across time and space? The next subsection presents summary statistics on potential explanatory variables of interest.

2.2.2. Policies and prices

Our study covers a period of substantial policy change likely to affect forest management. These include policies liberalizing trade, prices, agricultural and forest land tenure. The expected direction of the effect of these types of policies is unclear – in countries that are relatively more efficient in producing wood products, we would expect increases in trade liberalization to increase forest loss from logging, but this would not be the case for countries that are relatively inefficient in wood production. Fig. 2 shows the price and trade liberalization indices calculated by the EBRD. As was mentioned above, these indices are constructed to assess the progress towards a market economy (EBRD, 1990, 1995, 2000, 2005, 2010). Higher values indicate more liberalized price and trade policy, meaning that there is less government interference in the setting of domestic prices and fewer barriers to trade, such as tariffs and quantity restrictions. In order to get a sense of the cross-country variation, the figures group countries into those with initial values above and below the 1990 median for each of the indices. The figures show that most of the adjustments in price and trade policies occurred between 1990 and 1995, with little change thereafter.

In addition to trade and price liberalization, all of these countries changed their land tenure systems in fundamental ways. Just as with liberalization policies, the anticipated impact of more private land tenure should be an increasingly efficient allocation of land resources. For countries with forest or agricultural sectors that were initially inefficiently large (as was often the case with centrally managed agriculture), land privatization should decrease logging forest use and increase agricultural abandonment. However, in countries with wood or agricultural sectors that were under exploited during the socialist era, we would expect privatization to increase forest and agricultural activities. We exploit two separate measures to capture these changes: one for changes in agricultural land tenure and the other for private forest management. In the former case, we rely on the excellent work of Lerman et al. (2004a) and Hartvigsen (2014) who created an index of land reform to reflect the extent to which agricultural land policy approached private property in each of the transition countries. This index is available for 1995, 2000, and 2005; higher numbers indicate greater privatization. A table containing the full set of values for this index is contained in the appendix (Table A1).

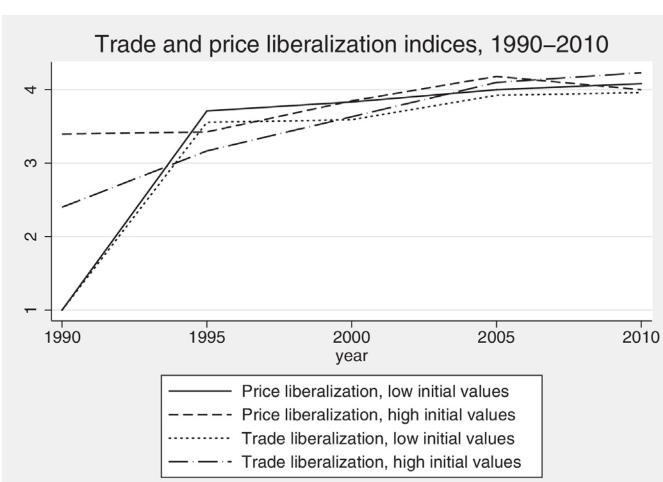


Fig. 2. Price and trade liberalization indices, 1990–2010. *Data source*: EBRD (2015).

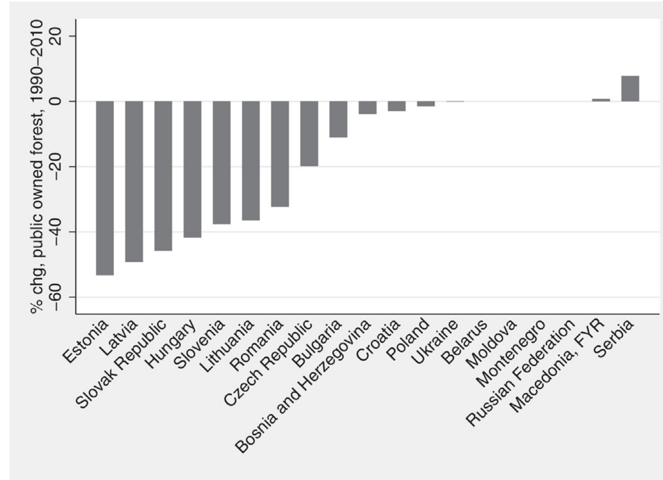


Fig. 3. Change in % public owned forest by country, 1990–2000. *Data source*: FAO (2010).

To indicate the extent to which forest was privately managed, data from the Food and Agriculture Organization provides values for the percentage of forest that is publicly owned in each country and year (FAO, 2010). The majority of countries in the sample either maintained or decreased the proportion of their forests owned by the state (Fig. 3). The largest privatizers are Estonia, Latvia, and the Slovak Republic and the only exceptions to this are Macedonia and Serbia.

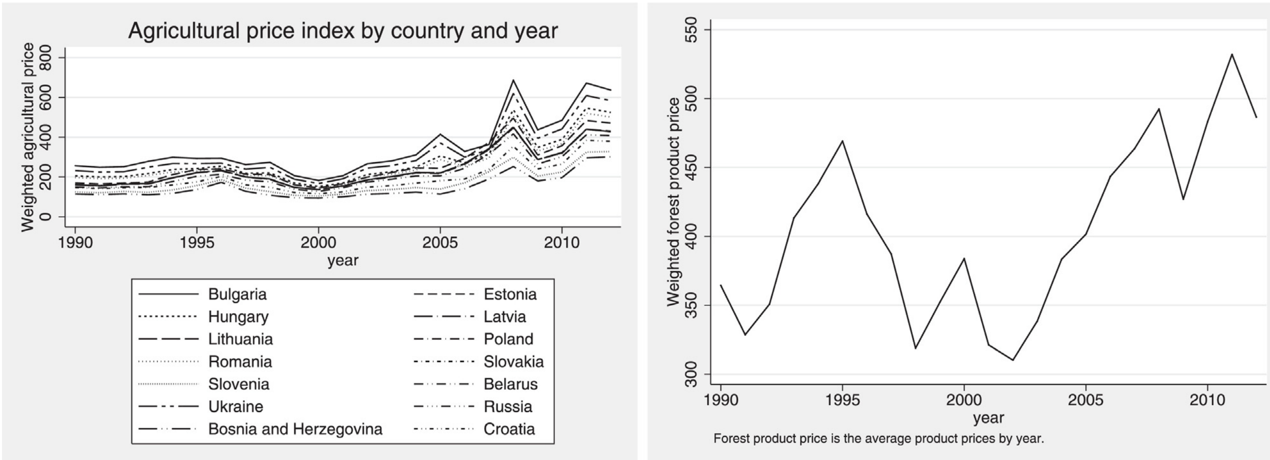
Finally, we compile data on both agricultural and forest prices, using commodity prices compiled by the International Monetary Fund (IMF) for the years from 1980 to 2015. For agricultural prices, we construct an index that reflects the weighted average of global agricultural prices faced by each country, where the weights are comprised of the percent area in production of each crop in the baseline period.[4] Because it is difficult to assess forest production amounts for different types of products, we have a single price index for the forest index that varies over time, and represents the average of major forest products including round wood, sawnwood, and pulpwood. Due to the difficulty of assessing production area for different types of wood, we are unable to create different forest price indices by country.

We extract two conclusions from visual examination of the price trends (Fig. 4). First, over the period of interest, global prices for both wood and agricultural products increased substantially. However, the similarity among the agricultural price indices suggests that, while some countries have a consistently more valuable composition of production, the overall trends in prices are very similar.

2.3. History and geography

We use a limited number of variables to represent geography and historical land management in our data. We limited the number of variables because of the relatively small number of countries involved, which precludes using large numbers of covariates. In addition, we find that most geographical variables are highly correlated; for example, low slope is collinear with having no limits to agriculture on a plot of land.

[4] The prices used to create these indices are nominal. However, the rise in prices is consistent with the increase in real prices of all commodities, which peaked around 2008 and has been documented by the IMF, FAO, and other institutions. The use of nominal prices is not problemmatic in our panel analysis, where time fixed effects absorb general inflationary trends.



(a) Agriculture (b) Forest

Fig. 4. Agricultural and forest product prices, 1990–2015. *Source*: International Monetary Fund (2015).

Countries with larger quantities of high quality agricultural land should produce more agricultural goods and have less forest exploitation. We captured this characteristic using data obtain from the European Soil Database and the Soil Geographical Database of Eurasia at a 1 km resolutionESDB (2004). For each country, we calculated the percentage of land in the category "no agricultural limitations", which excludes gravelly, lithic, saline, eroded, landfills, flooded or permafrost soils. We use this geographical attribute because it encapsulates a wide range of climatic, land use and substrate elements.[5]

To measure the influence of historical land management, we compute the percentage increase in crop and pasture land between 1850 and 1900, using data summarized from the History Database of the Global Environment Goldewijk (2001).[6] In Central Europe, population growth and the early industrialization resulted in substantial deforestation, starting in the 16th and 17th century (Williams, 2003). The perceived "timber crisis" prompted the rise of forestry in the 18th and 19th century, especially in France and Germany, and motivated the development of more aggressive forest management systems, including the wide-scale planting of spruce trees to foster timber production (Fernow, 1907). Our variable choice is motivated by the fact that increases in non-forest land use during this key period constituted a threat to forests at a time when fuelwood was crucial for many households and the demand for pulp and timber was rising (Williams, 2003; Maddison, 2007). Rotation age for pulp production in temperate Eastern Europe is roughly 70–90 years and 90–120 years for wood/timber (Disescu, 1954; Chirita et al., 1981). If planting of highly productive species (spruce, pine) occurred after forest cover reached its low point in the late 19th and early 20th century Munteanu et al. (2015), Kuemmerle et al. (2015), then these forests would be close to their rotation age in 2000.

Fig. 5 shows three sets of maps illustrating the distribution of land without agricultural limits (panel a), the increase in agricultural and crop land between 1850 and 1900 (panel b), and changes in the trade index over time. The highest percentage of agricultural land without limits is found in Ukraine, with similarly high percentages in the southwest of the study area. The Baltic states have notably moderate agricultural potential compared to the countries with better agricultural endowments, such as Hungary, Romania, Poland, and Ukraine. Historically, we observe the largest expansion of crop and pasture land in Ukraine between 1850 and 1900. Similarly large expansions occurred in Poland, Slovakia, and Russia. In terms of policy, trade liberalization, which is highly correlated with price liberalization, proceeded much more rapidly in the center, southeast, and Baltic States than in Russia, Ukraine, and especially Belarus.

2.4. Analysis

To understand the potentially independent effects of policy, geography, and history we apply two types of analysis: estimates of long-run, cross-sectional variation in forest loss from logging and forest gain over the entire period, and a secondary analysis that exploits temporal variation in forest loss from logging and key covariates.

The first approach is to run simple cross-sectional ordinary least squares regressions. We denote the dependent variable as ΔL_c, which can represent either forest loss from logging over the 1985–2010 period over the total forest area in 1985, or forest gain on non-forested land over the same period, normalized by the area of land in each country that was unforested 1985. We refer to the first as forest loss from logging and the second as agricultural land abandonment. While we recognize that this variable does not pick up all abandonment of agricultural production, it does measure increases in forest area on previously unforested land provided the forest was tall enough to be detected by satellite imagery. In European Russia, this means that land has to have been abandoned for at least 12 years and trees have reached a height of at least 6 m (Potapov et al., 2014). The estimation equation, run separately for each outcome, is:

$$\Delta L_c = \beta_0 + \beta_1 H_c + \beta_2 G_c + \boldsymbol{\beta}_3' \Delta \mathbf{P}_c + \epsilon_c \quad (1)$$

H_c represents history, for which we use as a proxy the percent change in crop and pasture land between 1850 and 1900. G_c is geography, the proxy for which is percentage of land with no agricultural limitations. $\mathbf{P}_c$ is a vector of policy variables measured in changes from 1985 to 2010, including the trade and price liberalization indices as well as, where appropriate, an index for agricultural land tenure. In specifications where the Balkans are included, there is an indicator variable for these countries to capture their very different time-path, which is likely correlated with conflict in the region over

[5] We attempted to use mean slope and elevation of each country as a proxy for "geography". However, neither of these variables had a significant effect on outcomes, and we suggest that the agricultural limitations data better represented a suite of factors indicating potential land productivity.

[6] We also computed for each country the percentage of land historically under Habsburg Rule, based on political boundaries of Eastern Europe at 1900 (Euratlas, 2010). This covariate, however, has little explanatory power.

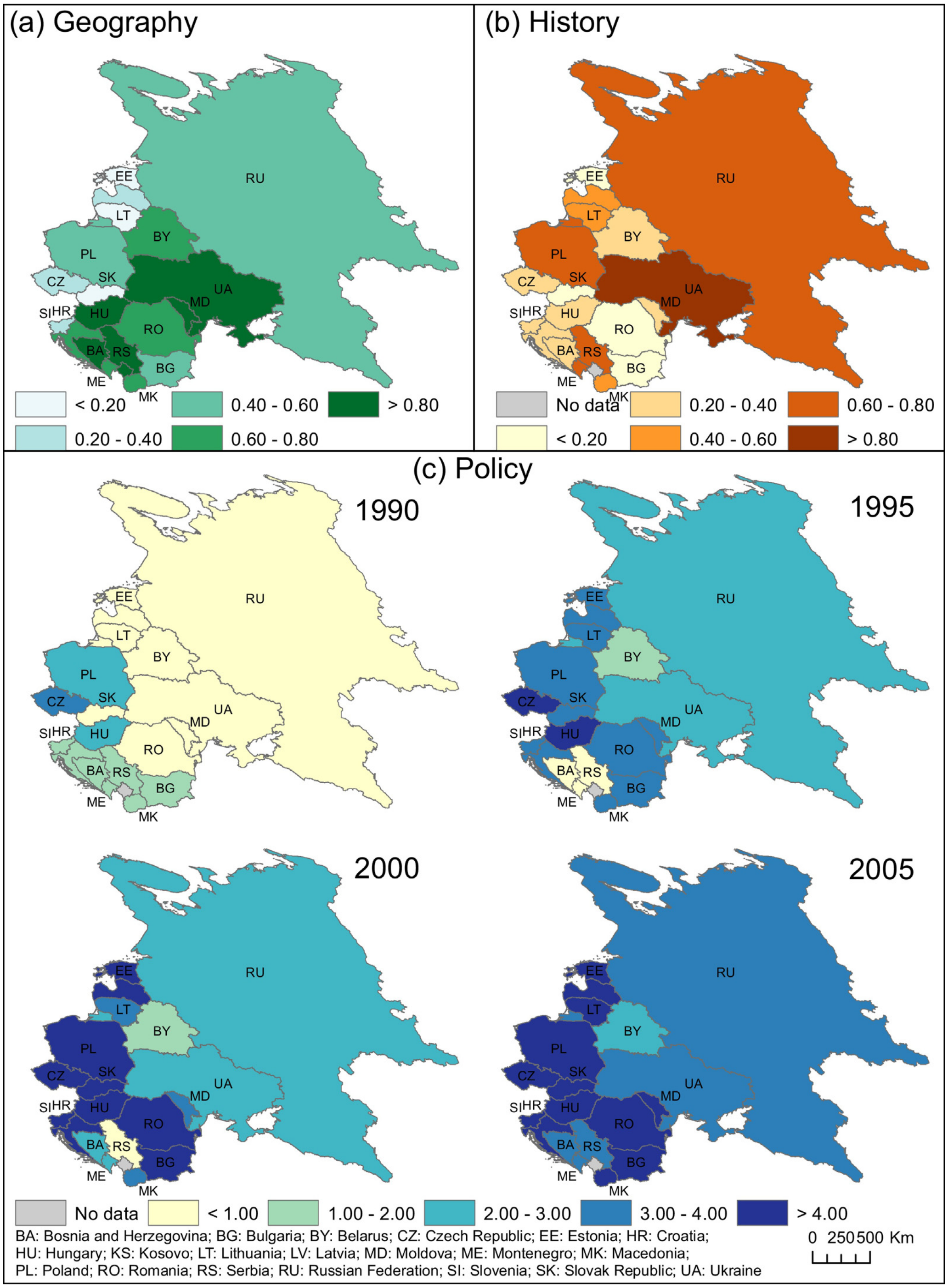


Fig. 5. Geography, history, policy. *Sources*: Geography: European Soil Database and Soil Geographical Database of Eurasia (2004); History: increase in crop and pasture land between 1850 and 1900, from History Database of the Global Environment (Goldewijk, 2001); Policy: EBRD Trade Index (2015).

the period analyzed. In the forest loss from logging regressions we include the percentage of forest that is publicly managed, and in the agricultural abandonment estimations we include the change in the land tenure index for agricultural land, which increases with improvements in private property rights. Note that factors that have the same change over time for all countries in our sample – such as world prices – are absorbed into the constant term.

In the second approach, we conduct panel regressions using the one outcome that has variation over time – i.e., forest loss from logging. In this case we summed forest loss over five period intervals, and implement fixed effects at the country level and time effects for each year. The estimation equation is:

$$\Delta L_{cp} = \alpha_0 + \beta'_3 \mathrm{P}_{cp} + \sum_{p=1990}^{2005} \mathrm{X}'_c \mathbf{I}^p \phi_p + \sum_c \gamma_c \mathrm{I}^c + \sum_p \rho_p \mathrm{I}^p + \mu_{cp}. \quad (2)$$

All time-invariant characteristics are subsumed by the country fixed effects ($\mathbf{I}^c$), and all covariates the same across all regions (like global prices) are absorbed by the period fixed effects ($\mathbf{I}^p$). The periods are denoted by their starting year 1985 (the reference category), 1990, 1995, 2000, and 2005. Only covariates that change across countries and time ($\mathbf{P}_{cp}$) can be included individually into the model. We test the effect of history (increase in crop and pasture land, 1850–1900) and geography (good agricultural

Table 2
Correlations between the two main dependent variables and studied independent variables.

	(1)								
	Total loss (%)	Gain (%)	Δ Trade index (%)	Δ Price index (%)	Δ Public-owned (%)	Δ Land index (%)	Δ crops 19c (%)	Balkans	No ag limits (%)
Total loss (%)	1								
Gain (%)	0.156	1							
Δ Trade index (%)	0.255	−0.228	1						
Δ Price index (%)	0.166	−0.156	0.676**	1					
Δ Public-owned (%)	−0.566*	−0.0951	−0.403	−0.0992					
Δ Land Index (%)	−0.167	0.283	0.0352	0.103	0.295	1			
Δ crops,19c (%)	−0.0294	−0.244	−0.0254	−0.123	0.526*	−0.152	1		
Balkans	−0.548***	0.175	−0.359	−0.526*	0.404	0.399*	0.225	1	
No ag limits (%)	−0.502**	0.0261	−0.331	−0.111	0.693**	0.201	0.296	0.405*	1

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
Data sources as described in Table B2.

land, as defined above) by interacting these covariates with the time dummies to examine whether or not places with these characteristics have differential time trends. This specification cannot estimate the importance of baseline variables, but allows for better identification of time variant covariates because the variation used to estimate the coefficients represents changes over time within countries. The price variables are averages for all countries, which means that they only vary with time. For this reason, the price variables are included only as interactions with the trade and price liberalization indices. Because of the conflict in the Balkan regions from 1991 to 2001, the estimations also include interactions between an indicator for Balkan countries and the time variables (coefficients not shown). Standard errors are clustered at the country level to account for serial correlation of the error term.[7]

Each of these approaches has its own advantages. The cross-sectional differences help identify long term trends in the data, and allow us to examine the impact of time-invariant variables on these trends. The panel analysis, on the other hand, controls for all time-invariant characteristics and helps us understand shorter term variation in harvesting decisions induced by temporal changes in the included variables. In both cases, we begin with a small number of covariates and gradually add all those of interest. The complete set of parameter estimates is shown in the appendix. Below we present estimates from the specifications which contain the greatest number of covariates together, but exclude the Balkan states due to the scarcity of data from these countries.

3. Results

3.1. Cross sectional results

This section shows results from cross sectional estimations, where the dependent variables are the total percent forest loss from logging relative to baseline forest area ("forest loss from logging") and the total increase in forested area on previously unforested land relative to the unforested baseline ("abandonment") from 1985 to 2010. Before we consider the results, it is useful to first examine the linear correlations among variables shown in Table 2. Means, standard deviations, minima and maxima of the variables used in analysis are contained in Table B2 in the appendix. Forest loss from logging is positively correlated with the trade and price liberalization indices. It is strongly negatively correlated with having publicly owned forest or being a Balkan state. Agricultural land abandonment is negatively correlated with liberalization and positively correlated with land quality, land reform, and being in the Balkans. Importantly, the explanatory variables are highly correlated with each other. The correlation between the trade and price indices is 0.69, and the relationship between the trade index and public forest ownership is −0.40. Being a Balkan state is negatively correlated with all of the policy variables of interest, and positively with cropland expansion during the late 19th century. Geography – the percentage of land with no agricultural limits – is highly correlated with outcomes as well as policy variables. The overall picture suggests that it is difficult to separate the effects of these different measures.

Tables B3 and B4 in the appendix show complete estimation results from Eq. (1). The coefficient estimates presented in Fig. 6 are marginal effects calculated at the mean values of the variables – that is, the effect of a one unit change in the covariate on the outcome, for the mean observation. For forest loss from logging, change in public ownership of forests and increases in agricultural/pasture area in the 19th century have significant effects.[8] Increases in agricultural and crop land between 1850 and 1900 increase logging in 1985-2012, and greater increases in public-owned forest decrease it. The magnitude of the impact is qualitatively larger for public forest ownership; the beta coefficient for this variable is −0.91, whereas for the historical covariate it is 0.62.[9] None of the variables have a significant effect on agricultural land abandonment.

The small sample size poses some limitations for our study. Given the standard errors of the estimates and the sample size, the minimum detectable effects for the trade and price indices in the forest loss regressions are more than six times larger than the estimated effect sizes (MDE for the trade index is 0.02 and for the price index 0.03).[10] A calculation of the necessary sample size needed to detect a statistically significant effect of the trade index on forest loss (given the point estimates and standard errors) yields a sample size of 42 for the trade index, and 968 for the price index. However, the same sample size calculations for the history and public-owned forest variables yield minimum sample sizes of 7 for both.

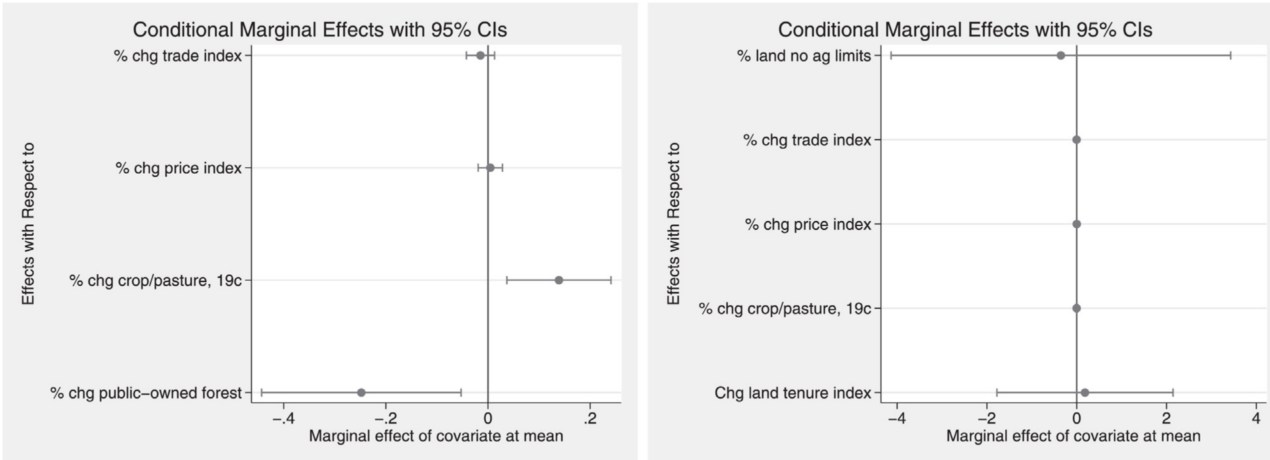
The adjusted R-squared values for the forest loss models vary between 0.19 and 0.31, while they are negative for agricultural

[7] We also attempted to use spatial regression methods, but the small number of countries in our sample made this infeasible.

[8] We also tried including the measure of land appropriate for agriculture and baseline forest area in these regressions. Neither had any discernible impact on the outcome.

[9] Beta coefficients are shown in the appendix, and indicate the effect of a one standard deviation change in a covariate on the outcome, also measured in standard deviations.

[10] Minimum detectable effects are computed using a power level of.80 and a significance level of.10 for a two tailed test. They can be interpreted as the smallest the smallest true impact that the estimation has a good chance of detecting. The MDEs for 19th century land use change and public-owned forest variables are 0.10 and 0.19, respectively.



(a) Forest loss from logging (b) Abandonment

Fig. 6. Cross-sectional impacts of key covariates. *Source*: Authors' own calculations using coefficients from Tables B3 and B4, column (5).

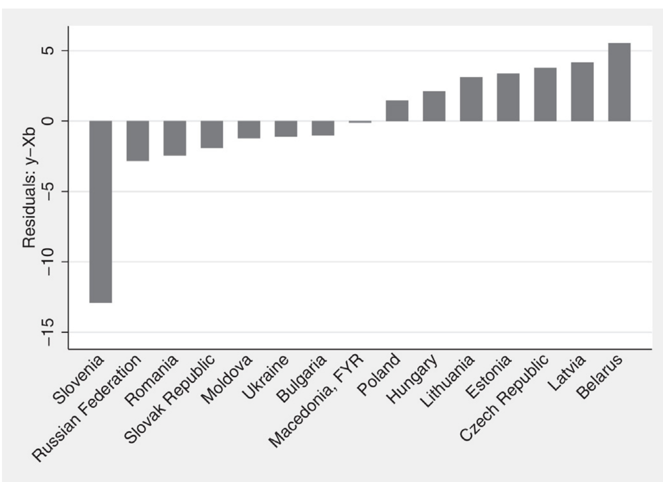


Fig. 7. Residuals from forest loss regression. *Source*: Authors own calculations using residuals from column (5), Table B3.

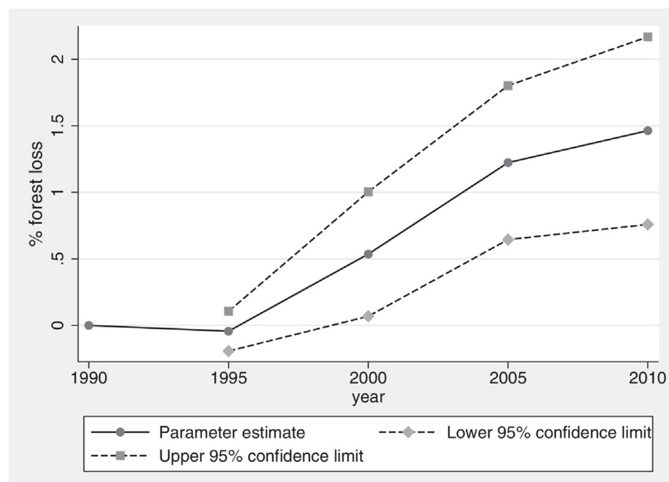


Fig. 8. Average forest loss due to logging by year across sample. *Source*: Authors' own calculations.

abandonment.[11] The countries with the largest residuals for forest loss from logging are Slovenia and Belarus (see Fig. 7). For Slovenia, the model predicts more deforestation than is actually present while for Belarus it presents less.

3.2. Panel results

Before looking at the panel specification in detail, it is important to note that the time effects by themselves absorb a significant amount of the variation in the data. A simple linear regression with time dummies for each period has an R-square of 0.20. These coefficients (Fig. 8) should be interpreted as the difference in the percentage of forest loss due to logging in a given time period relative to 1985–1990. There is no significant change in forest loss from logging between 1985–1990 period and 1990–1995, after which time loss increases steeply up until 2005, and then begins to level off.

The point estimates for the panel variables from column (9) of Table C5 (Fig. 9) show that the percent of publicly owned forest has a large negative and statistically significant marginal effect. The history variables are increasingly significant over the time steps.[12]

4. Discussion

In this paper we have sought to examine whether differences in liberalization policies, geography, or history can explain variation in forest loss from logging and forest regrowth on abandoned lands across Eastern Europe and European Russia. Our main conclusion is that while historically determined rotational cycles and forest privatization are important explanatory variables for forest loss from logging, none of our covariates helps explain the variation in agricultural land abandonment. The minimum detectable effect sizes discussed above suggest that this at least partially a problem of small sample size and lack of variation in the price and

[11] Note that can occur when the explanatory variables have no actual explanatory power, since the adjusted R-squared formula given n observations and k regressors has the formula $\frac{1-(1-R^2)(n-1)}{(n-k-1)}$, where the R-squared in formula is the actual reported R-squared.

[12] Note that these have been rescaled to proportional changes rather than percent changes. We did not plot the point estimates for the liberalization indices because the confidence intervals were so wide they made it difficult to see the effects of the statistically significant variables.

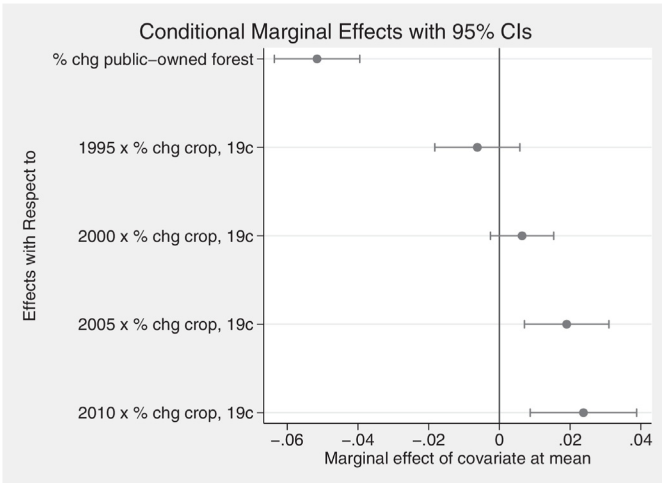


Fig. 9. Panel impacts of key covariates. *Source*: Authors' own calculations using coefficients from Table C5, column (9).

trade liberalization indices. However, this is not just a limitation of our methodology, but also a reflection of broad-scale, concomitant changes. All of these countries experienced significant but similar restructuring of their economies. Almost all of them made major policy changes, some of which occurred simultaneously, making it difficult to separate out signals from different types of policies. This does not mean that policy and geography do not matter. Indeed, land use change across the time period that we examine was substantial, but it was substantial across all of the countries in the sample due to the common shocks, many of them drastic policy changes, that occurred after the collapse of socialism in 1991. In comparison to the magnitude of these shocks, the small differences in rates of price and trade liberalization across countries, and cross-sectional variation in geography do little to explain the observed differences in rates of forest extraction and agricultural abandonment.

It is true, however, that the increases in public-owned forest consistently decrease forest logging. One possible explanation for this is that in countries that privatized more forest, pre-privatization logging was inefficiently low. In addition, forest privatization is a policy that is, according to our correlation matrix, not very highly correlated with other liberalization policies. Whether higher rates of logging after privatization are desirable or not is a question our study was not designed to answer. On one hand, there are economic benefits to increasing timber production. However, before we conclude that forest management privatization yields greater productivity, it bears mentioning that greater forest loss from logging can also undermine conservation efforts when privatization results in the harvesting of forests with high conservation value, as was the case in Romania (Knorn et al., 2012, 2013).

It also bears mentioning that the public ownership variable could be picking up an omitted variable: increases in trade uncorrelated with changes in actual trade policy as measured by the trade index. Clearly, the privatization of forest was particularly rapid and widespread in the Baltic states (see Fig. 3). These countries also experienced increasing demand for wood exports, possibly for reasons unrelated to their own trade policy. Finland and Sweden, for example, introduced increasingly more stringent environmental regulations affecting the forestry sector in the early 2000s, possibly increasing demand for imported wood over this period. Indeed in Estonia, Lithuania, and Latvia, timber exports did increase at the same time, and this has been attributed to import demand from neighboring countries, at least partially due to a strong forest conservation policy introduced in Finland during this time (Nylund, 2010; Mayer et al., 2005). Wood exports to Scandinavian countries from Estonia and Latvia peaked between 1997 and 2000, when forest loss from logging also increased. Similar circumstances occurred in Lithuania around 2007 (see Fig. D.1).

In addition to the public ownership variable, we were fascinated by the relative importance of historic land use on contemporary rates of forest loss from logging. Indeed, the effect of changes in land use in the late 19th century seems to explain a large part of the current forest extraction. We hypothesize that increasing agricultural land use during this period put pressure on forests, creating a perceived shortage to which governments reacted with a large scale planting of trees. Because the chosen species had long rotation cycles, this results in relatively large amounts of harvesting as the forests reached the end of their cycles ten years after the collapse of the Soviet Union. This is an interesting finding, because it suggests that major drivers of observed landscape changes may find their roots in choices made by previous generations – a lesson we would do well to acknowledge when designing current environmental management policies (Munteanu et al., 2015).

The lack of importance of geographical variables was also surprising, given their key role in explaining land use allocations and changes within countries.[13] However, our results suggest that such covariates are better suited to explaining micro phenomena than country-level outcomes. Summarizing geography with basic statistics over such large areas is bound to reduce the interesting variation, and this is likely one of the reasons for the insignificance of the geographical variables in our results. In other words, we do not posit that geographical characteristics are not important, but rather that their importance is not visible in correlations measured using aggregations at a country-scale.

5. Conclusion

The collapse of socialism in 1991 was one of the most substantial natural experiments in social change that has occurred in modern history. All of the countries in Eastern Europe experienced this shock, and went through major transitions and restructuring in their policies, governance, and economics. Among the different countries, there was considerable variation in when certain policies, such as trade liberalization, were implemented, how land ownership was restructured, and how quickly market economies were established. However, our result show, and this came as a surprise to us, that these differences mattered very little in terms of their effects on rates of forest loss from logging and forest regrowth on former agricultural lands. The only specific policy variable that had a clear effect was the rate at which forests were privatized. Ultimately, the magnitude of the common political and economic shock was much larger than the magnitude of the effects of individual countries' approaches to liberalization. What did matter though were legacies of historic land use, as far back as a century before the collapse. This suggests that in order to understand, and potentially predict, future land use change, it will be important to put future changes into the context of past uses, and to account for the likelihood of major socioeconomic shocks.

Acknowledgements

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[13] There is a large and rich literature on this topic. An accessible framework is presented by Angelsen (2009), and a nice summary of the policy-relevant analysis is presented in Pfaff et al. (2009).

Appendix A. Land reform indices

Table A1
Agricultural land tenure system.

Country	Year	Land reform index	Privatization strategy	Potential private land ownership	Allocation strategy	Transferability	Farm organization
Hungary	1995 2000 2005	9 9	Distribution restitution	All land	Plots	Buy/sell lease	Individual corporate
Romania	1995 2000 2005	7 8 8	Distribution restitution	All land	Plots	Buy/sell lease	Individual corporate associations
Bulgaria	1995 2000 2005	7 8 8	Distribution	All land	Plots	Buy/sell lease	Individual corporate associations
Estonia	1995 2000 2005	6 8	Restitution	All land	Plots	Buy/sell lease	Individual corporate
Latvia	1995 2000 2005	7.6 9	Restitution	All land	Plots	Buy/sell lease	Individual corporate
Lithuania	1990 2000 2005	7 8	Restitution	All land	Plots	Buy/sell lease	Individual corporate
Poland	1990 2000 2005	8 8	Sell state land	All land	Plots	Buy/sell lease	Individual corporate hh plots
Czech Republic	1995 2000 2005	8 8	Restitution	All land	Plots	Buy/sell lease	Individual corporate
Slovakia	1995 2000 2005	7 8	Restitution	All land	Plots	Buy/sell lease	Individual corporate
Slovenia	1995 2000 2005	9 9	Restitution				
Russia	1995 2000 2005	5 6 6	Distribution	All land	Shares	Lease	Corporate, individual
Belarus	1995 2000 2005	1 2 2	None	Household plots only	None	Use rights non-transferable	Corporate, individual
Ukraine	1995 2000 2005	5 5 5	Distribution	All land	Shares to plots	Lease	Corporate, individual
Moldova	1995 2000 2005	6 8 7	Distribution	All land	Shares to plots	Buy/Sell lease	Corporate, individual
Croatia	1995 2000 2005	5 8 8					
Serb&M	1995 2000 2005	 5 8					
Macedonia	1995 2000 2005	7 7 7					
Bosnia HG	1995 2000 2005	 6 7					
Albania	1995 2000 2005	8 8 9	Distribution	All land	Plots	Buy/Sell lease	Individual

Appendix B. Basic summary statistics and cross sectional regressions

The table below shows basic summary statistics for the variables used in analysis.

Each column of each table below represents a separate ordinary least squares regression. Table B3 shows results from a regression of percent total forest loss from logging on a variety of variables. The statistics in parentheses are beta coefficients, which show the change in the outcome, in terms of standard deviations, with a one

Table B2
Summary statistics.

	mean	sd	max	min
Total loss (%, 1990–2010)	11.008	6.260	23.961	3.499
Gain (%, 1990–2010)	1.859	1.291	5.322	0.204
Δ Trade Index (%, 1990–2010)	185.627	120.395	333.000	8.250
Δ Price index (%, 1990–2010)	142.931	148.978	333.000	−45.504
Δ Public-owned (%, 1990–2010)	−18.163	21.056	7.771	−53.217
Δ Land index (%, 1990–2010)	0.190	0.274	1.000	0.000
Δ Crops, 19c (%, 1990–2010)	43.578	24.582	98.825	7.524
Balkans (0/1)	0.211	0.419	1.000	0.000
No ag limits (%, 1990-2010)	0.568	0.272	0.940	0.080
Trade liberalization index, baseline	1.737	0.872	4.000	1.000
Price liberalization index, baseline	2.387	1.289	4.000	1.000
Land liberalization index, baseline	6.625	2.029	9.000	1.000
Publicly owned forest, baseline (%)	89.540	18.562	100.000	37.205
Observations	19			

Data sources: Forest loss: Potapov et al. (2014); Trade and price indices: EBRD (2015); Land index: Lerman et al. (2004a) and Hartvigsen (2014); 19c crops: History Database of the Global Environment Goldewijk (2001); publicly owned forest: Food and Agriculture Organization (2010).

Table B3
Cross-section regression on percent of total forest loss from logging.

Variables	(1)	(2)	(3)	(4)	(5)
Balkans (0/1)	−8.358***	−7.827***	−9.488***	−9.761***	
	(−0.559)	(−0.524)	(−0.635)	(−0.653)	
% forest, 1985	0.0461				
	(0.102)				
Δ Trade index (%)		0.00349	0.0135	0.0130	−0.0147
		(0.0671)	(0.259)	(0.250)	(−0.317)
Δ Price index (%)			−0.0144	−0.0141	0.00459
			(−0.342)	(−0.336)	(0.111)
Δ Crops, 19c (%)				0.0210	0.139**
				(0.0824)	(0.599)
Δ Public-owned (%)					−0.248**
					(−0.883)
Observations	19	19	19	19	15
R-squared	0.310	0.304	0.357	0.363	0.435
Adjusted *R*-squared	0.224	0.217	0.228	0.181	0.208

Robust normalized beta coefficients in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$ Dependent variable is % forest loss. All regressions contain a constant.

Table B4
Cross-section regression on agricultural land abandonment.

Variables	(1)	(2)	(3)	(4)	(5)
No ag limits (%)	−0.254	−0.254	−0.630	−0.193	−0.353
	(−0.0535)	(−0.0535)	(−0.132)	(−0.0407)	(−0.0993)
Δ Trade Index (%)			−0.00308	−0.00230	−0.00263
			(−0.288)	(−0.215)	(−0.344)
Δ Price Index (%)			0.00107	0.000519	0.000274
			(0.124)	(0.0599)	(0.0403)
Balkans (0/1)	0.606	0.606	0.586	0.641	
	(0.197)	(0.197)	(0.190)	(0.208)	
Δ Crops,19c (%)				−0.0145	−0.00232
				(−0.277)	(−0.0608)
Δ Land Index (%)					0.184
					(0.0490)
Observations	19	19	19	19	15
R-squared	0.033	0.033	0.076	0.143	0.105
Adjusted *R*-squared	−0.0879	−0.0879	−0.188	−0.187	−0.393

Robust normalized beta coefficients in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Dependent variable is percent of forest gain after cropland. All regressions contain a constant.

standard deviation change in the independent variables, which are listed in the first column of the table. Stars indicate statistical significance against a null hypothesis of the coefficient being equal to zero.

The next outcome of interest is total percent forest gain between 1985 and 2010 on land which was not previously in forest. These results are contained in Table B4. Again, there is little statistical significance across these covariates. Tellingly, the adjusted *R*-squared is negative, which is evidence for the weakness of the covariates in explaining the variation across countries.

Appendix C. Panel regressions

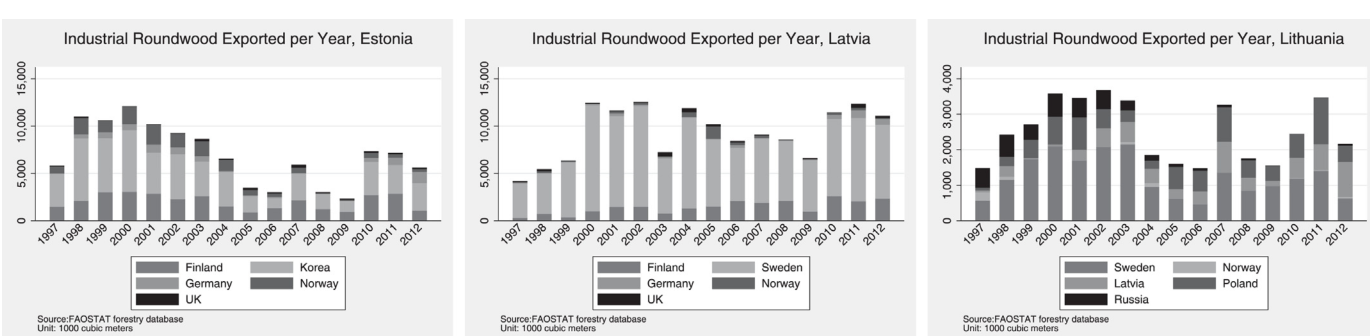
The results in Table C5 show various estimations of the panel model. Fig. 9 shows the marginal effects of the coefficients evaluated at the mean of the covariates from the estimation in column (9).

Appendix D. Supplemental figures

Table C5
Panel regression on percent of forest loss from logging.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Trade liberalization	0.106	0.211		−2.879	−0.311	−0.398	1.845	1.262	−0.231*
	(0.0925)	(0.185)		(−2.514)	(−0.271)	(−0.347)	(1.533)	(1.048)	(−0.192)
Price liberalization		−0.155	−0.526		−0.206	−0.726	1.347	1.847	0.0864
		(−0.112)	(−0.379)		(−0.148)	(−0.523)	(0.956)	(1.310)	(0.0613)
Δ ag, 1850–1900 × period ending in 1995						−0.00140	−0.00236	0.00382	−0.00624
						(−0.0207)	(−0.0299)	(0.0483)	(−0.0789)
Δ ag, 1850–1900×period ending in 2000						0.00126	0.0105	0.0138*	0.00641
						(0.0186)	(0.151)	(0.199)	(0.0924)
Δ ag, 1850–1900×period ending in 2005						−0.000872	0.00584	0.0148**	0.0190***
						(−0.0129)	(0.0885)	(0.224)	(0.288)
Δ ag, 1850–1900×period ending in 2010						0.00520	−0.00125	0.0149	0.0238***
						(0.0767)	(−0.0189)	(0.225)	(0.360)
Percent of public-owned forest								−0.0445***	−0.0516***
								(−0.677)	(−0.785)
Trade liberalization×ln(wood price)				−1.262	−1.308	−1.384	−0.972	−0.727	
				(−6.692)	(−6.939)	(−7.338)	(−4.917)	(−3.677)	
Trade liberalization×ln(ag price)				2.010**	1.604	1.702*	0.805	0.571	
				(9.794)	(7.814)	(8.290)	(3.747)	(2.658)	
Price liberalization×ln(wood price)			−1.549		−1.239	−1.180	−0.551	−0.547	
			(−6.765)		(−5.412)	(−5.151)	(−2.374)	(−2.359)	
Price liberalization×ln(ag price)			1.826*		1.388	1.425	0.354	0.252	
			(7.357)		(5.591)	(5.739)	(1.409)	(1.005)	
Observations	95	95	95	95	95	95	87	87	87
R-squared	0.591	0.598	0.610	0.630	0.646	0.649	0.559	0.690	0.644
Number of country_code	19	19	19	19	19	19	19	19	19
Country FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES	YES	YES

Robust normalized beta coefficients in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.
Dependent variable is percent deforestation by year. Year dummy variables are included individually but not shown. All regressions include a constant also not shown.



(a) Estonia (b) Latvia (c) Lithuania

Fig. D.1. Exports of roundwood from the Baltics to top 5 importers. *Source*: Food and Agriculture Organization (2010).

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