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Regional- and district-level drivers of timber harvesting in European Russia after the collapse of the Soviet Union

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ABSTRACT

After the collapse of the Soviet Union, the forestry sector in Russia underwent substantial changes: the state forestry sector was decentralized, the timber industry was privatized, and timber use rights were allocated through short- and long-term leases. To date, there has been no quantitative assessment of the drivers of timber harvesting in European Russia following these changes. In this paper we estimate an econometric model of timber harvesting using remote sensing estimations of forest disturbance from 1990–2000 to 2000–2005 as our dependent variable. We aggregate forest disturbance to administrative districts – equivalent to counties in the United States – and test the impact of several biophysical and economic factors on timber harvesting. Additionally, we examine the impact that regions – equivalent to states in the United States and the main level of decentralized governance in Russia – have on timber harvesting by estimating the influence of regional-level effects on forest disturbance in our econometric model. Russian regions diverged considerably in political and economic conditions after the collapse of the Soviet Union, and the question is if these variations impacted timber harvesting after controlling for district-level biophysical and economic drivers. We find that the most important drivers of timber harvesting at the district level are road density, the percent of evergreen forest, and the total area of forest. The influence of these variables on timber harvesting changed over time and there was more harvesting closer to urban areas in 2000–2005. Even though district-level variables explain more than 70 percent of the variation in forest disturbance in our econometric model, we find that regional-level effects remain statistically significant. While we cannot identify the exact mechanism through which regional-level effects impact timber harvesting, our results suggest that sub-national differences can have a large and statistically significant impact on land-use outcomes and should be considered in policy design and evaluation.

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1. Introduction

Russia is important globally as a supplier of forest goods and services: it contains 20 percent of the world's forests or close to 800 million hectares of forestland (FAO, 2010). Nearly 60 percent of all Russian harvested timber comes from European Russia, even though this area accounts for just 20 percent of forest stock within the country (Serebryanny and Zamotaev, 2002). One reason for this heavy exploitation is that European Russia is more accessible than Siberia due to better road infrastructure, and since the collapse of the Soviet Union, has been an important exporter to Western Europe and former Union Republics (UNECE and FAO, 2003).

Timber production affects other forest services, such as biodiversity and carbon. The temperate forests of European Russia are high in plant diversity and many animal species depend on these forests for habitat (Kuemmerle et al., 2011). Additionally, both the boreal and temperate forests of Russia have been identified as large carbon sinks (Liski et al., 2003; Houghton et al., 2007).

After the collapse of the Soviet Union in 1991, the forestry sector in Russia underwent significant changes: forest management and administration were decentralized to local and regional administrators and the timber industry was privatized. The first official forestry legislation in post-Soviet Russia was the 1993 Principles of Forest Legislation. Under this legislation, the state maintained responsibility for forest management activities such as sanitary cuts, thinning, and reforestation, while former state logging enterprises and wood processing centers were privatized. Ownership of natural resources was excluded from privatization

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but user rights, specifically the right to lease forests for industrial logging, were regulated in 1992 (Nysten-Haarala, 2001). Leases for timber concessions could be short-term – less than five years – or long-term – up to 49 years. The responsibilities of the leaseholder under these initial contracts were limited to harvesting activities with maintenance and reforestation delegated to the state forestry sector until 2007 (Torniainen and Saastamoinen, 2007).

In addition to changes to property rights, forest management and administration were initially decentralized to local forest administrators in 1993 (Krott et al., 2000; Eikeland et al., 2004). Local forestry units operate on a scale roughly equivalent to administrative districts – equivalent to counties in the United States – in Russia. Poor forest management and inefficient utilization characterized these first few years of transition. These outcomes were largely due to the lack of technical skills and training provided to local state employees and legislation that took away the primary source of funding for local forestry employees: timber harvesting. These changes in budgets created perverse incentives for local managers to charge high taxes and fees in timber contracts and to illegally cut timber to sell (Krott et al., 2000; Eikeland et al., 2004; Torniainen et al., 2006). These additional taxes and fees adversely affected the private timber industry. In addition, procuring markets for products and finding investment capital proved difficult for newly privatized firms (Pappila, 1999; Kortelainen and Kotilainen, 2003).

In 1997, Russia issued its first Forest Code, which recentralized decision-making authority to the regional – equivalent to states in the United States – level in Russia. This shift in authority away from local forest administrators helped reconcile the problem of high taxes and fees by making contracts between firms and the state more transparent. However, it failed to address the perverse incentives faced by local forestry units to cut timber illegally through the guise of sanitary logging in order to generate income (Torniainen et al., 2006). In 2004, the central government recentralized forest authority, paralleling national shifts to regain control of regions. In 2007, Russia released its latest version of the Forest Code. This new Forest Code once again decentralized decision-making powers to the regional level and made the first substantive changes to forest property rights, designating several new responsibilities to firms and extending the duration of leases up to 99 years (Torniainen and Saastamoinen, 2007).

Despite what we know about institutional changes within the forestry sector, there has been no quantitative analysis of the drivers of forest disturbance across European Russia since the collapse of the Soviet Union. Identifying these drivers is important in order to understand the spatial and temporal patterns of land-use changes and the impacts they might have on timber supply, biodiversity, and carbon sinks. There have been a few remote sensing analyses of forest disturbance in European Russia since 1991, which indicate the spatial pattern of forest loss. One study analyzes the effect of privatization of formerly protected forests on forest fragmentation and loss around Moscow city (Boentje and Blinnikov, 2007) and reports that between 1991 and 2002 about 15 percent of forest was cut in the environs around Moscow city. Another study estimates forest disturbance in 42 regions in European Russia between 2000 and 2005 (Potapov et al., 2011) and identifies hotspots of forest cover change around Moscow city and St. Petersburg. However, remote sensing by itself does not provide information about the drivers of forest disturbance. In this paper we combine remote sensing data of forest disturbance from 1990–2000 and 2000–2005 with economic theory of timber supply and statistically estimate the drivers of commercial logging in European Russia using an econometric model.

We base our empirical analysis on the neoclassical economic theory of forest rotation: the single-rotation Faustmann formula. This informs our selection of control variables in our econometric model, and allows us to assess whether timber harvesting in post-

Soviet Russia was responsive to market forces. Since transition, the forestry sector, similar to other industries in Russia, has struggled to fully integrate into the market economy. Logging rates have declined and continue to remain relatively low within Russia. In 2003, forest output was approximately 23 percent of annual allowable cut and the industrial forest sector's contribution to national gross domestic product was only about 3 percent (Torniainen et al., 2006). While forest output began to increase in the late 1990s, paralleling a national increase in economic growth, it is not clear whether timber firms began responding to economic determinants of timber supply, especially given the development of the informal economy within the timber industry (Carlsson et al., 2000; Olsson, 2008).

To examine how differences across regions may have impacted forest disturbance we estimate the effect of regions on remaining variation in forest disturbance from our econometric model. Changes in the Russian forestry sector mirrored broader institutional changes within Russia after the collapse of the Soviet Union: governance was decentralized to the regional level and most businesses were privatized. Regional administrative powers were formalized in 1991, allowing regions to elect their own governors until 2005. The ability of regions to implement and enforce fair and transparent legislation led to divergences in institutional and political conditions among Russian regions (Stoner-Weiss, 1997; Hanson and Bradshaw, 2000; Slinko et al., 2005). This led to differences in privatization effectiveness and overall economic productivity and development at the regional level (Selowsky and Martin, 1997; Berkowitz and DeJong, 2003; Yakovlev and Zhuravskaya, 2008; Brown et al., 2009). Given these significant institutional, political, and economic changes across Russian regions, we test whether regional-level effects impacted land cover conditional on district-level determinants of timber supply. This lets us assess whether broader institutional, political, or economic factors, in addition to economic and biophysical drivers at the district-level, shaped land-cover changes in Russia.

2. Theory

Since the majority of forest disturbance in European Russia is due to timber harvesting (Potapov et al., 2011), we use the neoclassical economic theory of timber supply, i.e., the Faustmann formula, to inform the selection of control variables in our econometric model. The Faustmann formula gives the economically efficient rotation period for a timber stand under a market system with well-defined property rights. Private timber firms were constrained by principles of profit maximization in post-Soviet Russia (Pappila, 1999; Kortelainen and Kotilainen, 2003), unlike the Soviet period where firms did not internalize the costs of production (Brown and Wong, 1992). The Faustmann formula can be used to derive the optimal rotation period for a stand under infinite rotation or from a single rotation period. In Russia, forest property rights allowed timber to be leased for a maximum of 49 years and the majority of leases were for five years or less before 2007 (Torniainen, 2009). Given this short duration of property rights, the opportunity costs of delaying future harvests and the costs of replanting a timber stand were not internalized by firms, and the problem faced by decision-makers can be modeled as the decision to maximize the present value from a single rotation.

The optimal single rotation problem for a timber stand with time-varying prices¹ is:

$$\max \pi = [P(T)X(T)e^{-\delta T}], \quad (1)$$

¹ The Faustmann formula is typically derived for time-invariant prices. However, time-varying prices better fits our empirical specification since we are considering a 15-year period.

where π is profits; $P(T)$ is timber price net harvesting costs at time T ; $X(T)$ is the timber volume at harvest time T ; and δ is the discount rate. For a timber stand, k , the optimal rotation period is found by taking the first order condition with respect to T , which gives:

$$\begin{aligned} \text{MNB}_{T,k,\text{cleared}} & \left(P(T), \frac{dP(T)}{dT}, X(T), \frac{dX(T)}{dT}, \delta \right) \\ & = \frac{dP(T)}{dT} X(T) + \frac{dX(T)}{dT} P(T) - \delta P(T) X(T) \end{aligned} \quad (2)$$

where $\text{MNB}_{T,k,\text{cleared}}$ is the marginal net benefit of clearing a stand k in time T .

The parameters $P(T)$, $X(T)$, T and δ in Eq. (2) impact a timber firm's decision to cut a stand when faced with market conditions. Net prices, $P(T)$, vary as a function of the value of timber and the capital costs of timber harvesting (Binkley, 1987). The value of timber varies by the type (e.g., coniferous versus deciduous) and quality of trees harvested. Capital costs of harvesting are affected by access to timber and transportation costs. In the land-use change literature, accessibility to timber is typically measured using biophysical variables such as elevation or slope (Chomitz and Gray, 1996; Cropper et al., 2001; Müller and Munroe, 2008). Typical measures of transportation costs include road density and distance to roads or major markets. Timber volume, $X(T)$, can be measured as total forest cover or growing stock. The time dummy variable, T , captures any factors that vary across time, such as the global price of timber, which would affect the decision of when to harvest a stand.

The discount rate, δ , has a dual function: it captures the rate of return necessary to cut the timber stand and the opportunity costs of investing in timber harvesting. Its importance in determining the optimal time to cut timber can be found by solving Eq. (2) for δ :

$$\frac{dP(T)/dT}{P(T)} + \frac{dX(T)/dT}{X(T)} = \delta \quad (3)$$

Eq. (3) illustrates that the optimal time to cut a stand is when the rate of return from the stand equals the rate of return elsewhere in the economy, i.e., the discount rate. Regional differences in privatization effectiveness and the economic returns from non-forestry activities are two ways in which regional-level effects would impact the discount rate. Regional differences in privatization effectiveness refer to differences in the risk and uncertainty that timber firms would face by working in that region; risk and uncertainty increase the discount rate on resource extraction decisions. This can lead to an increase or decrease in harvesting depending on the capital-intensity of timber extraction (Farzin, 1984). Alternative economic activities in a region would impact the opportunity costs of investing in timber harvesting; we expect to see less timber harvesting in regions where alternative activities yielded high rates of return.

3. Study area and data

3.1. Study area

Two of the main administrative subdivisions in Russia are federal subjects – referred to as regions in this paper – and rayons – referred to as districts in this paper (Fig. 1). Regions are equivalent to states in the United States and are the main level of decentralized governance in the Russian Federation. Districts are equivalent to counties in the United States and are under the purview of regions.

This analysis focuses on the temperate and boreal forests of European Russia (Fig. 2). The study area covers about 3 million km² and approximately 42 percent of this area is forested. The northern part of the study area is predominately evergreen forest, dominated by coniferous species such as spruce, fir, and Siberian pine. Further south, deciduous forest dominates, with species such as oak, lime, ash, maple, and gray alder. There is a large proportion

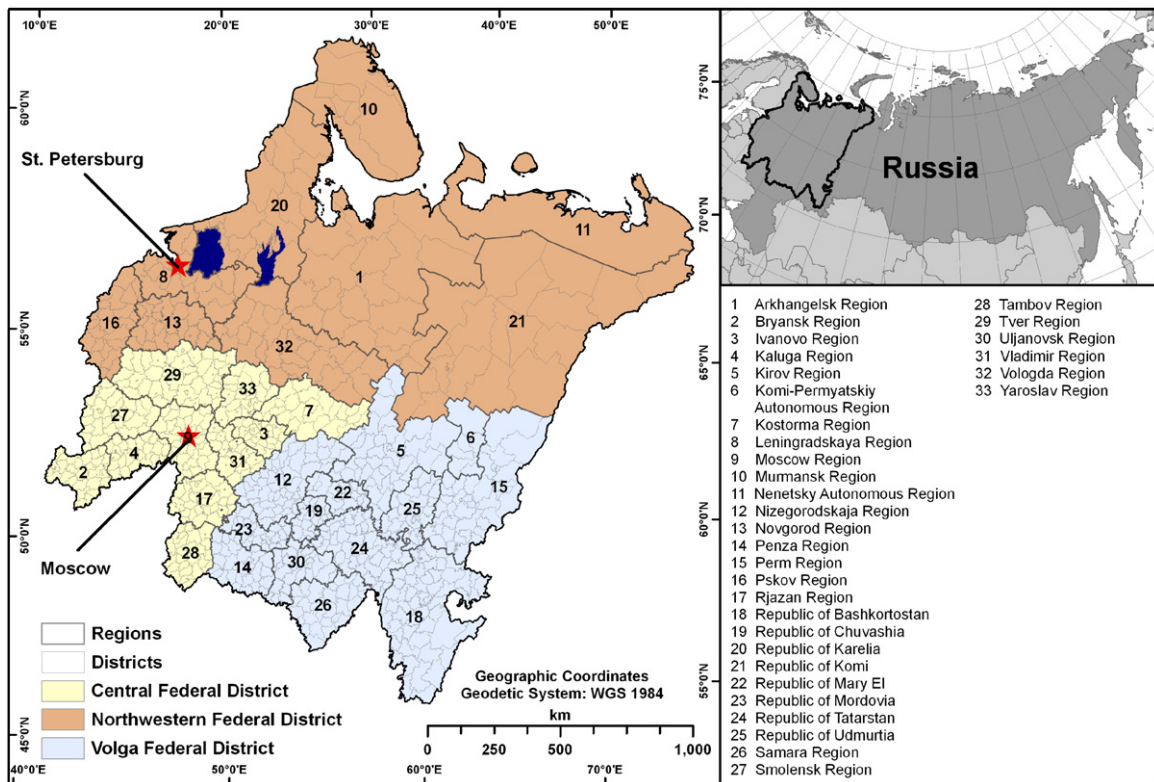


Fig. 1. Map of political units in our study area in European Russia.

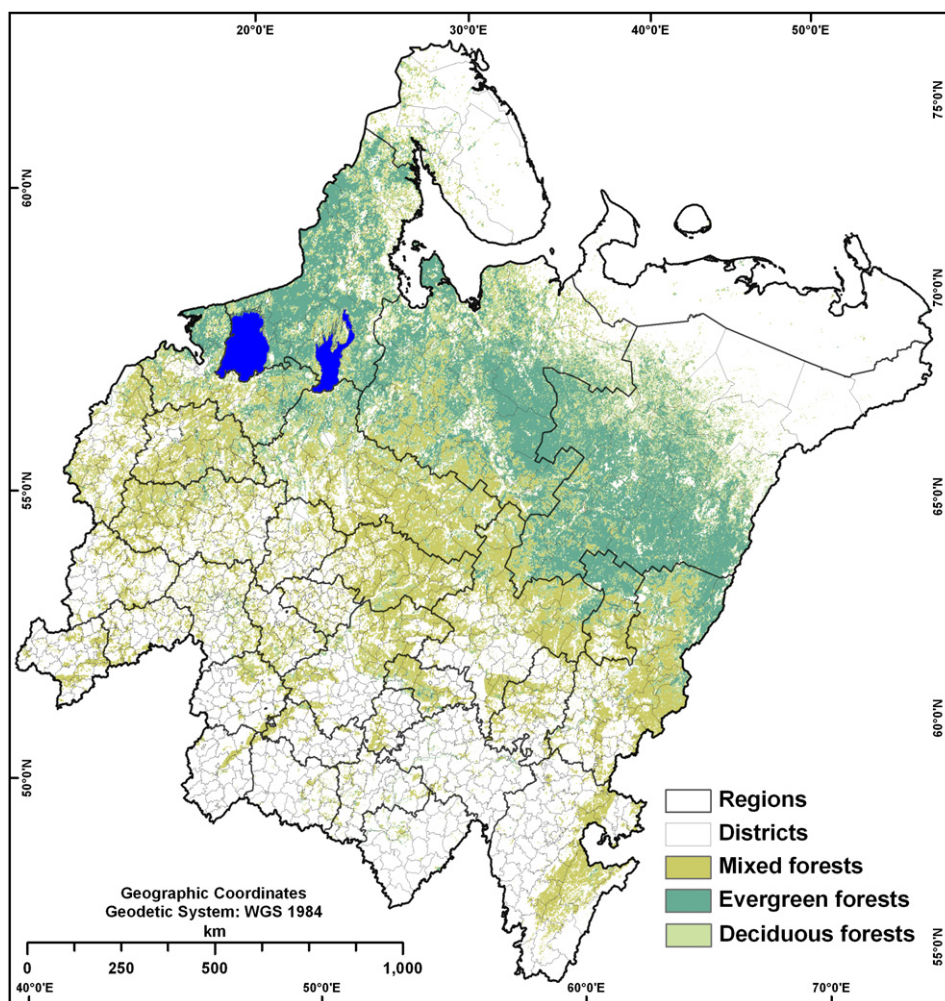


Fig. 2. Map of forest types in our study area in European Russia.

of forest classified as “mixed” forest throughout the study area. These forests consist predominately of deciduous species but include patches of evergreen forest. The extreme northern part of this study region is predominately tundra, with little to no forest cover. The study area covers 33 regions in European Russia and 895 districts (Fig. 1); since 5 of these districts had no forest in 1990 they were excluded from the analysis, giving a total sample size of 890 districts.

3.2. Data

The dependent variable is the annualized area within a district that was converted from forest to non-forest between 1990–2000 and 2000–2005 (Table 1). Data on forest disturbance come from two secondary sources: a Greenpeace-Russia classification of forest disturbance from 1990–2000 (Yaroshenko et al., unpublished results) and a forest disturbance classification from 2000–2005 (Potapov et al., 2011). Both forest disturbance maps use Landsat satellite images to map the area of forest change. Using these measures allows us to mitigate concerns about misreported logging rates associated with national statistics on timber (World Bank, 2004; Ottitsch et al., 2005). While we have remote sensing data for both time periods, the total number of regions and districts covered by the two analyses varies slightly. In 1990–2000, there are data on 26 regions and 599 districts; in 2000–2005, there are data on all 33 regions and 890 districts in our study area (Fig. 1). This gives a total sample size of 1489 observations. The average

value of forest disturbance over the entire study period was 6.4 km² per year.

A description of each independent variable used in the econometric model and the source of the data are described in Panel A of Table 1; summary statistics are found in Panel B. To measure timber stock, $X(T)$, we use total forest area in a district. While total forest cover is not an exact measure of growing stock, statistics on growing stock in Russia are not available at disaggregated levels and suffer from measurement error (Kinnunen et al., 2007). Since there was no measure of total forest in the 1990–2000 Greenpeace-Russia dataset, we recreate this value by adding the area of forest disturbance from 1990–2000 to 2000 forest area. Given the greater land-use change process of afforestation in Russia following transition (Lerman et al., 2004), this might result in a slight overestimation of forest cover for 1990. The average area of forest cover in our sample is 1921 km².

To control for differences in net prices, $P(T)$, we use the following measures: percent evergreen forest, slope, road density, and distance to nearest market (defined as either Moscow or St. Petersburg). To measure the percent of evergreen forest we use Moderate Resolution Imaging Spectroradiometer imagery (MODIS) data. These data are from 2005 and are representative of the relative proportion of evergreen trees in the study area between 1990 and 2005. The average district in the study area has about 47 percent evergreen forest. Slope is measured using NOAA's Global Land 1-km Base Elevation Project and the average district in this study has a variation in slope of less than one degree. Because slope

Table 1
Description, data source, and summary statistics for district-level covariates.

Variable	Description	Data source			
Panel A: Description and data source					
Forest disturbance	Area (km ²) converted from forest to non-forest between 1990–2000 and 2000–2005; authors create the annual area of forest disturbance by dividing total area in 1990–2000 by ten and dividing total area in 2000–2005 by five	1990–2000 data from Greenpeace-Russia (Yaroshenko et al., unpublished results) and 2000–2005 data from Boreal Forest Monitoring Project (described in: Potapov et al., 2011)			
Forest area	Total forest area (km ²) in 1990 and 2000	2000 measure from Boreal Forest Monitoring Project and 1990 measure recreated by authors (see text)			
Evergreen	Percent of evergreen forest in 2005; time-invariant	Moderate Resolution Imaging Spectroradiometer imagery data			
Slope	Average variation in slope (degrees); time-invariant	NOAA's Global Land 1-km Base Elevation Project			
Road density	Total length of roads (m) in a district divided by area of that district (m ²); time-invariant	1:500,000 topographic maps			
Market	Distance (km) from the center of a district to closest market, defined as either Moscow city or St. Petersburg; time-invariant	Calculated by authors			
Time dummy	Takes a value of "0" for 1990–2000 and a value of "1" for 2000–2005	Authors' creation			
Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Panel B: Summary statistics					
Forest disturbance (km ²)	1489	6.40	15.32	0	215.73
Forest area (km ²)	1489	1921.04	3719.96	0	33,957.32
Evergreen (%)	1489	0.47	0.36	0	1
Slope (degrees)	1489	0.74	0.57	0	5.78
Road density (m/m ²)	1489	0.01	0.03	0	0.40
Market (km)	1489	532.54	330.41	0	1837.00
Time dummy	1489	0.5	0.5	0	1
Panel C: Log-transformed summary statistics					
Forest disturbance	1489	1.18	1.11	0	5.38
Forest area	1489	6.32	1.94	0	10.43
Evergreen	1489	0.36	0.25	0	0.69
Slope	1489	0.52	0.24	0	1.91
Road density	1489	0.01	0.03	0	0.34
Market	1489	6.03	0.82	0	7.52

and elevation are highly correlated in our study area, we only use slope in equations presented in this paper. Road density is measured as the total length of all roads (in meters) in a district divided by the total land area of the district (in m²); road data are from topographic maps of Russia produced around the collapse of the Soviet Union. Distance is calculated from the center of each district to either Moscow city or St. Petersburg, depending on which is closest. The average distance is 533 km.

We include a time dummy, *T*, in the analysis to capture time-varying and spatially invariant unobservables, such as global timber prices or timber export prices. *T* takes on a value of "0" for the 1990–2000 time period and a value of "1" for the 2000–2005 time period. We do not have explicit data on factors expected to impact the discount rate, i.e., differences in regional privatization effectiveness or alternative economic opportunities. Instead, we use the structure of the econometric model (described in Section 4) to estimate the regional-level influence on timber harvesting.

4. Calculation

4.1. Estimating district-level drivers of forest disturbance

We construct a reduced-form empirical equation using Eq. (2) as a motivation for variable selection, recognizing that the total area cleared in a district is the sum of many stand-level harvesting decisions. Since we expect both district- and regional-level factors to affect timber supply, we use the multilevel linear model, also known as the hierarchical linear model or two-level generalized linear model, because it explicitly accounts for multiple levels of data. Since we have data from two time periods, we estimate a longitudinal or panel data multilevel model (Frees, 2004; Cameron and Trivedi, 2005). The multilevel model is estimated using maximum restricted likelihood.

We specify the multilevel model for two levels: a level-two regional-level effect and a level-one district-level effect (Rabe-Hesketh and Skrondal, 2008). The level-one model can be expressed as:

$$Y_{ijt} = \varphi_{0j} + \gamma P_{ijt} + \beta X_{ijt} + \vartheta T_t + d_{ij} + \varepsilon_{ijt}, \tag{4}$$

where Y_{ijt} is the amount of forest disturbance in a district *i* nested in a region *j* at time *t*; φ_{0j} is the time-invariant region-specific effect; P_{ijt} is a vector of covariates measuring net prices at the district level; X_{ijt} is a vector of covariates measuring timber stock at the district level; T_t is a time dummy variable capturing time-varying and spatially invariant unobservables across 1990–2000 and 2000–2005; d_{ij} is the time-invariant district-level effect; ε_{ijt} is the time-varying residual error; and γ , β , and ϑ are parameters to be estimated. The level-two, or region-specific, effects enter Eq. (4) as:

$$\varphi_{0j} = \delta_{00} + \mu_{0j} \tag{5}$$

μ_{0j} is the time-invariant region-specific random effect and δ_{00} is the average outcome for the population. Combining these two equations gives:

$$Y_{ijt} = \delta_{00} + \gamma P_{ijt} + \beta X_{ijt} + \vartheta T_t + d_{ij} + \mu_{0j} + \varepsilon_{ijt} \tag{6}$$

An important assumption of the multilevel model is that d_{ij} , μ_{0j} , and ε_{ijt} are independent.

An advantage of multilevel models is that they relax the assumption of independence between observations by decomposing the error term into hierarchical components – in this study districts are nested within regions – and then imposing a structure on the variance and covariance of these terms. This has emerged as a strategy to correct for spatial autocorrelation when the correlation has a nested structure (Anselin, 2002) and has been used in several recent land-use change studies (for example: Hoshino, 2001; Pan and Bilsborrow, 2005; Vance and Iovanna,

2006; Overmars and Verburg, 2006). In this study, the structure of the multilevel model controls for correlations across districts within the same region; for this to fully account for spatial autocorrelation, regions must be independent of one another (i.e., no correlation in timber harvesting across regions). To test this assumption we use Moran's I; Moran's I tests for spatial autocorrelation in model residuals across a matrix of spatial weights, or neighborhoods, which are determined by the researcher. We generate a spatial weights matrix based on the latitude and longitude from the center of each region. If the null hypothesis of zero spatial autocorrelation is not rejected in model residuals, then we have confidence that the nested structure of the multilevel model accounts for spatial autocorrelation.

To estimate Eq. (6) we annualize forest disturbance, since this eases interpretation of parameter coefficients. This does not change the results since it is just a linear transformation of the data. Given the skewed distribution of forest disturbance and forest cover toward zero, we log-transform the dependent variable and all covariates. Since these are the values used to estimate parameter coefficients in Section 5, we present summary statistics for log-transformed variables in Panel C of Table 1.

The time dummy variable controls for any time-varying and spatially invariant unobservables, and also controls for any overlap in satellite images from the two assessments and any differences between how the two data sets were created.² As long as there is no systematic correlation between the overlap of images or differences in the two methodologies and our independent variables, then the time dummy variable controls for any unexplained variation across time periods and our parameter estimates are unbiased. We estimate two specifications for Eq. (6): as presented above and with interactions between all parameters and the time dummy variable. The former specification assumes that covariates have the same impact on timber harvesting across both time periods; the latter specification allows slopes to vary across time periods and lets us test whether covariates have different effects over these two periods.

In addition, we parameterize the two different specifications of Eq. (6) for two sample sizes: the full sample and after omitting Moscow region. Forest disturbance around Moscow city is driven in part by urbanization, rather than harvesting to maximize profits from the timber stand (Boentje and Blinnikov, 2007; Potapov et al., 2011). In general, remote sensing analysis detects all forest disturbances, some of which may not be from logging. Potapov et al. (2011) conclude in their analysis of forest disturbance from 2000 to 2005 that losses due to wildfires, wind damage, pests, and disease were relatively small. Data on forest disturbance in 1990–2000 excluded losses due to windfall and fire but not from urbanization, pests, or disease. Thus, changes in forest area from urbanization around Moscow city may have also affected this earlier remote sensing assessment and so we exclude this region as a robustness check.

By estimating Eq. (6) without any covariates (i.e., by restricting γ and β equal to zero; also known as the null model) we can calculate the unconditional intraclass correlation coefficient and the proportional reduction in total residual variance for the specifications with covariates (i.e., R^2 for the multilevel model). Rabe-Hesketh and Skrondal (2008, p. 58) give the formula for the intraclass correlation as:

$$\hat{\rho} = \frac{\hat{\psi}}{\hat{\psi} + \hat{\theta} + \hat{\omega}} \quad (7)$$

² Even though the remote sensing analyses are for two discrete time periods, the year of the satellite images used in the assessments may overlap. For example, the 2000–2005 assessment uses images from 1999 to 2002 to measure 2000 forest cover (Potapov et al., 2011). Additionally, the two assessments are known to vary in their classification algorithms and in the sampling design used for their training data.

where $\hat{\psi}$ is the estimated variance from the regional-level effect, μ_{0j} ; $\hat{\theta}$ is the estimated variance from the district-level effect d_{ij} ; and $\hat{\omega}$ is the residual variance from ε_{ijt} . As written, this formula gives the percent of variation in forest disturbance attributable to regions; the amount attributable to districts and observations is found by substituting the appropriate variance component into the numerator. Following this notation and the assumed independence of the three components of the error structure, the total variance from the null model can be calculated as:

$$\hat{\eta}_0 = \hat{\psi} + \hat{\theta} + \hat{\omega} \quad (8)$$

Letting $\hat{\eta}_1$ represent the total variance from Eq. (6) with covariates, the formula for R^2 is given in Rabe-Hesketh and Skrondal (2008, p. 102) as:

$$R^2 = \frac{\hat{\eta}_0 - \hat{\eta}_1}{\hat{\eta}_0} \quad (9)$$

4.2. Estimating regional-level effects on forest disturbance

While regions are treated as random effects in Eq. (6), and therefore a unique value for each region is not generated, Rabe-Hesketh and Skrondal (2008, p. 77) describe a method using maximum likelihood estimation that can generate unique coefficients and standard errors for each of the regional intercepts, μ_{0j} . Briefly, this method assumes that the estimated parameter values from Eq. (6) (i.e., for γ , β , and ϑ), and the district-level random error term, are the true values, and that the regional-level error term is the only unknown parameter in the model. With parameter values for γ , β , and ϑ , and the random effect, d_{ij} , held at their estimated values in Eq. (6), regional-level coefficients and standard errors are estimated that maximize the likelihood of the observed responses of timber harvesting. With these estimated parameters for each region we can calculate the size, sign, and statistical significance of each region on the remaining variation in timber harvesting. These estimated values can be interpreted as the influence a region has on the remaining variation in timber harvesting, after controlling for district-level covariates and the district-level random effect.

5. Results and discussion

5.1. District-level drivers of forest disturbance

Before considering the econometric estimates, we first provide a description of the total amount of forest disturbance in the 33 regions in the study area between 1990 and 2005 (Fig. 3). From 1990 to 2005, approximately 73,400 km² of forest was cut. With about 1.3 million km² of forest in the study area, this equates to disturbance in about 5.3 percent of the forest. From 1990 to 2000 the total forest area cut was about 51,500 km² with an average annual percent change of 0.25; total forest disturbance from 2000 to 2005 was about 21,900 km² with an average annual percent change of 0.27. However, these values ignore the fact that the total number of districts varies across the two time periods. If we restrict the total number of districts in 2000–2005 to those covered in 1990–2000, we find that the total area cut in 2000–2005 was about 20,700 km² with an average annual percent change of 0.32. One reason for the higher percent change in 2000–2005 is that more timber was cut in districts with less forest cover (Fig. 2). The number of districts with more intensive logging (i.e., higher annual percent change) also differs across time: 22 districts had more than one percent annual change in forest cover in 2000–2005 compared to only 4 in 1990–2000.

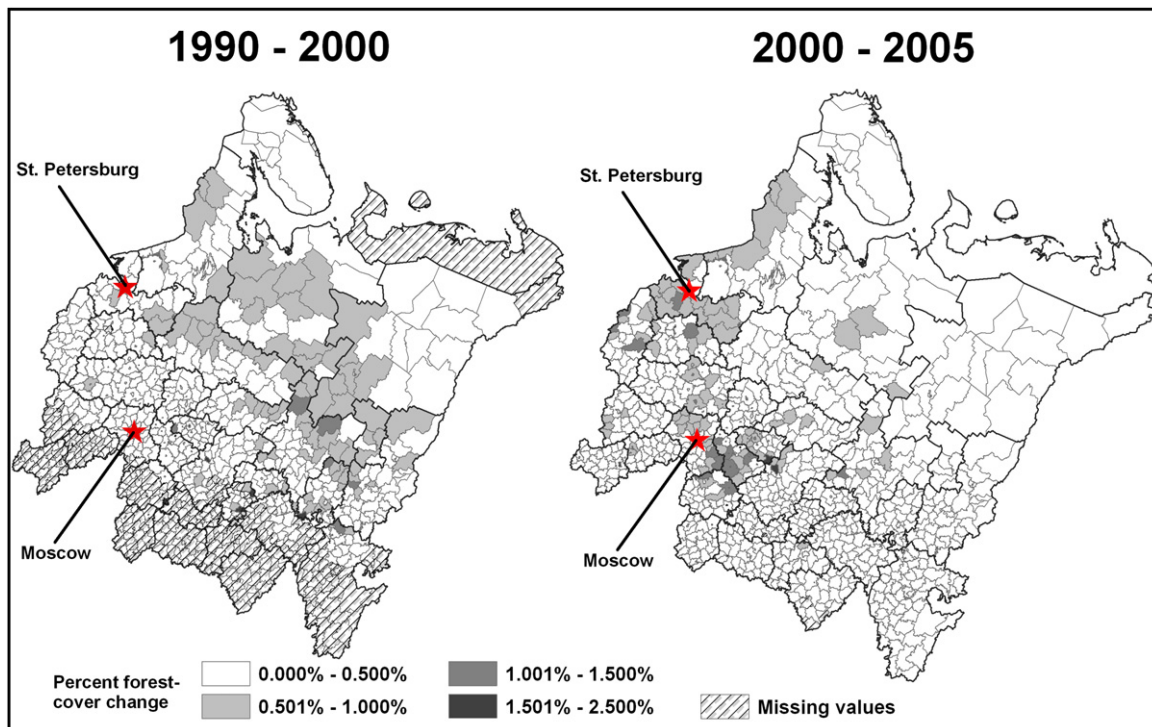


Fig. 3. Map of annualized percent change in forest cover in study area for 1990–2000 and 2000–2005. Annualized area (km^2) of forest disturbance is normalized by total forest area (km^2) in that district.

Spatially, in 1990–2000, areas with higher annual percent change in forest cover occurred predominately in the northern part of the study area, which is characterized by more evergreen forest and higher forest cover (Fig. 2). In 2000–2005, there was a noticeable shift in forest disturbance away from these areas and toward urban centers like Moscow city and St. Petersburg. Potapov et al. (2011) conclude that for 2000–2005, forest disturbance around Moscow city was predominately driven by urbanization, whereas around St. Petersburg forest disturbance was primarily due to commercial logging. While forest disturbance in the vicinity of Moscow city may be in response to urban development (Boentje and Blinnikov, 2007), disturbances in the greater Moscow region and in surrounding regions in 2000–2005 would be attributable to commercial logging. Thus, Fig. 3 suggests that where timber harvesting occurred shifted between these two time periods.

Turning to the econometric results, we calculate the proportion of variation in forest disturbance explained by time-invariant regional-level characteristics as 47 percent, by time-invariant districts as 31 percent, and by time-varying district characteristics (the residual error) as 21 percent in the null model (Table 2). While the percent of variation attributable to regions is the highest, we cannot attribute all of this variation to regional-level characteristics like differences in political or economic conditions. This high proportion of variation also reflects the fact that districts within the same region tend to be more similar than districts across regions, and thus justifies the use of a multilevel model.

Using Specification 1, which assumes that the effect of covariates is the same across both time periods, we find that all covariates have a statistically significant effect on forest disturbance at the 99 percent confidence level (Table 2). As expected, forest cover has a positive effect on forest disturbance; districts with more forest experience more timber harvesting. The percent of evergreen forest also has a positive effect on logging with a coefficient around one. All evergreen trees in the study region are coniferous species, and these are preferred for timber harvesting in Russia because they are better suited for the pulp and paper mills.

The impact of variation in slope is negative: areas with more variability in slope experience less logging.³ Variation in slope reflects the difficulty, and thus costs, of accessing timber stands. Road density has a positive effect and has the largest impact of any covariate. The magnitude of this effect reflects the fact that road infrastructure is a limiting factor for the timber industry in Russia; more roads lowers transportation costs and thus increases net prices of timber harvesting. The sign on distance to closest market is positive: areas farther away from Moscow city or St. Petersburg experience more forest disturbance. The covariates for Sample 2 are statistically similar to those in Sample 1. Even though parts of Moscow region might be an outlier in terms of reasons for forest disturbance (i.e., urbanization versus commercial logging), excluding this region does not change the magnitude or statistical significance of the drivers of timber harvesting in our study. Using Eq. (9), and the total variation in Panel C, we find that this specification explains about 71 percent of the variation in forest disturbance. In Panel D, the null hypothesis that there is no spatial autocorrelation in model residuals cannot be rejected (p -value for Moran's $I = 0.09$).

In Specification 2 we include time interactions for all variables and use the Wald test in Panel D to test the null hypothesis that all time-dummy interactions are equal to zero (Table 2). The Chi^2 value indicates that we can reject the null hypothesis: the regression functions are not the same across the two time periods. Since there are interaction terms in the model, to estimate the marginal effect of the covariates in 2000–2005 we take the derivative of forest disturbance with respect to that covariate in 2000–2005; these values are found in Panel B. The value of the coefficient in Panel A without the time interaction (for example,

³ Similar econometric results are found using the average value and standard deviation of slope. Additionally, we explored adding elevation to the model, but slope and elevation are highly collinear (correlation coefficient >0.8). Including elevation, instead of slope, in the econometric model results in similar estimates as those presented in Table 2.

Table 2
Econometric results for district-level drivers of forest disturbance.^a

Variable name	Specification 1			Specification 2	
	Sample 1 Coefficient (Std. error)	Sample 1 Coefficient (Std. error)	Sample 2 Coefficient (Std. error)	Sample 1 Coefficient (Std. error)	Sample 2 Coefficient (Std. error)
Panel A: Regression output					
Ln(Forest area)		0.347*** (0.013)	0.342*** (0.014)	0.358*** (0.016)	0.355*** (0.017)
Ln(Forest area) * time dummy				-0.019 (0.015)	-0.023 (0.015)
Ln(Evergreen)		0.986*** (0.086)	1.003*** (0.089)	1.101*** (0.104)	1.118*** (0.107)
Ln(Evergreen) * time dummy				-0.179* (0.095)	-0.189** (0.095)
Ln(Slope)		-0.558*** (0.094)	-0.573*** (0.096)	-0.475*** (0.111)	-0.560*** (0.114)
Ln(Slope) * time dummy				-0.083 (0.096)	0.032 (0.098)
Ln(Road density)		4.855*** (0.719)	4.706*** (0.726)	6.206*** (0.850)	6.150*** (0.852)
Ln(Road density) * time dummy				-2.378*** (0.802)	-2.594*** (0.789)
Ln(Market)		0.221*** (0.042)	0.222*** (0.052)	0.387*** (0.044)	0.431*** (0.055)
Ln(Market) * time dummy				-0.329*** (0.027)	-0.396*** (0.034)
Time dummy	0.086*** (0.024)	0.100*** (0.023)	0.062*** (0.023)	2.346*** (0.161)	2.728*** (0.200)
Constant	1.162*** (0.161)	-2.504*** (0.267)	-2.447*** (0.322)	-3.676*** (0.277)	-3.887*** (0.337)
Panel B: Marginal effect for 2000–2005					
Ln(Forest area) + Ln(Forest area) * time dummy				0.339*** (0.014)	0.332*** (0.014)
Ln(Evergreen) + Ln(Evergreen) * time dummy				0.923*** (0.092)	0.930*** (0.094)
Ln(Slope) + Ln(Slope) * time dummy				-0.558*** (0.098)	-0.528*** (0.101)
Ln(Road density) + Ln(Road density) * time dummy				3.828*** (0.791)	3.556*** (0.795)
Ln(Market) + Ln(Market) * time dummy				0.058 (0.044)	0.035 (0.053)
Panel C: Variance components					
Regional-level error	0.904	0.341	0.345	0.330	0.340
District-level error	0.600	0.326	0.338	0.352	0.360
Residual error	0.410	0.402	0.390	0.351	0.342
Total variation	1.35	0.38	0.39	0.36	0.36
R ²		0.71	0.71	0.74	0.73
Panel D: Test statistics					
Wald test (Chi ² value)				248.40	207.85
Moran's I (p-value)		0.09	0.09	0.11	0.10
Panel E: Sample size					
Number of observations	1489	1489	1414	1489	1414
Number of districts	890	890	850	890	850
Number of regions	33	33	32	33	32

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

^a The dependent variable is the log-transformed value of the annualized area of forest disturbance. Specification 1 presents results without time interactions and Specification 2 includes time interactions for all covariates. For both specifications we estimate the model for the full sample (i.e., Sample 1) and after omitting Moscow region (i.e., Sample 2). Since all variables are log-transformed the coefficient estimate can be interpreted as the percent change in area of forest disturbance for a one percent change in the independent variable (i.e., the elasticity of timber supply). In Specification 2, the 2000–2005 coefficients are in Panel B. The Wald test (Panel D) tests the null hypothesis that all time-dummy interaction terms equal zero. Moran's I tests the null hypothesis of no spatial autocorrelation in model residuals; we specify the weights matrix as the latitude and longitude for the center of each region.

Ln(Forest area)) represents the marginal effect of the covariate in 1990–2000. To test for statistical differences in the drivers of timber harvesting across time we compare coefficients in 1990–2000 (Panel A) to coefficients in 2000–2005 (Panel B). We do not find a statistically significant difference in the size of the forest cover, evergreen forest, or slope coefficients over time. Thus, the effect of biophysical factors on timber harvesting remains similar. However, the impact of transportation costs – road density and distance to market – on harvesting does change over time. The impact of road density, while significant and positive in both time periods, is

slightly larger for 1990–2000 than for 2000–2005. The impact of distance to markets is positive and significant in 1990–2000 but not statistically significant in 2000–2005. The percent of variation explained in this model is higher than in Specification 1, with an R² of 0.74. The null hypothesis that there is no spatial autocorrelation in model residuals cannot be rejected (p -value for Moran's I = 0.10).

In sum, the drivers of forest disturbance in European Russia between 1990 and 2005 are consistent with neoclassical economic theory of timber supply. More timber harvesting occurred in European Russia where: (a) there is more forest cover, (b) there is

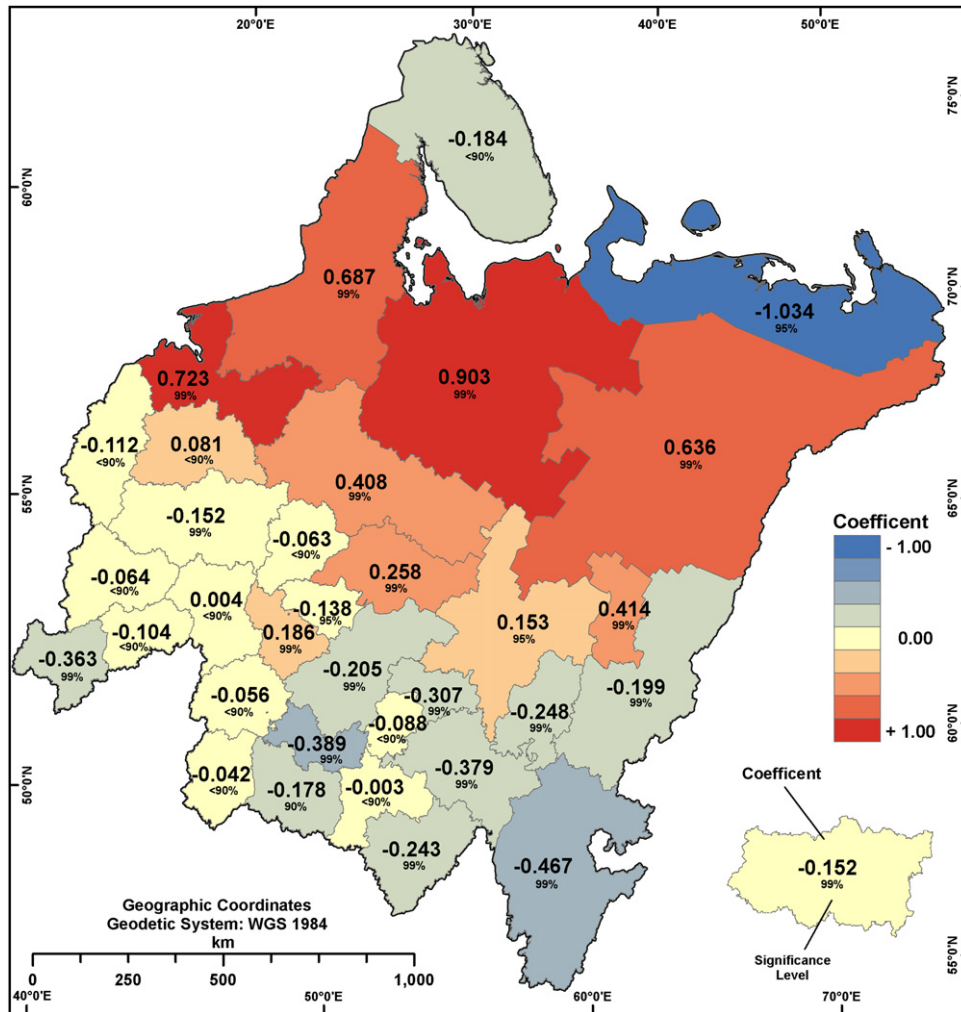


Fig. 4. Map of magnitude and significance of regional effects on forest disturbance.

more valuable timber (i.e., evergreen species), and (c) the costs of harvesting are lower (i.e., road density is higher and slope is less variable). The only effect that is counter to neoclassical economic theory is the sign on distance to markets: based on the theory, districts closer to markets should have more harvesting. However, in Specification 2 where we allow slopes to vary across time, we find that distance to markets is only statistically significant in 1990–2000; the coefficient in 2000–2005 (Table 2, Panel B) is insignificant. This change in the effect of distance on harvesting over time, along with the visible shift in the percent of forest disturbance in Fig. 3 toward Moscow city and St. Petersburg, implies that forest harvesting started to shift closer to market centers in 2000–2005. These results hold even when we exclude Moscow Region (Sample 2), indicating that this result is not driven by urbanization around Moscow City. The 2000–2005 result is more in-line with economic theory and suggests that timber firms became more responsive to harvesting costs; this result also suggests that where timber harvesting will have the biggest impact on other ecosystem services, such as biodiversity and carbon, is changing.

5.2. Regional-level effects on forest disturbance

When we estimate a unique coefficient and standard error for each region using maximum likelihood, we find that two-thirds of regions in our study have a statistically significant effect on the

remaining variation in forest disturbance (Fig. 4). Eleven regions have a positive effect on forest disturbance and 22 regions have a negative effect. The magnitude of this effect varies from a positive value of 0.9 to a negative value of 1; most of these values are statistically significant at a confidence level of 95 or 99 percent. These values represent the mean residual for a region, so for Arkhangelsk Region (Fig. 1), a value of 0.9 implies that, on average, the log-transformed value of forest disturbance in a district in this region is 0.9 higher than the log-transformed value of forest disturbance in the overall sample. There is a noticeable clustering of positive regional-level effects in the northern part of the study area (i.e., the Northwestern Federal District in Fig. 1) and more variation in the direction of influence and statistical significance of regional-level effects in the Central and Volga Federal Districts. However, in general, after controlling for district-level biophysical and economic determinants of timber supply, we find that regional differences impact land-use changes.

Section 2 outlines some possible reasons why we might expect to see these regional-level effects. These include regional divergences in privatization effectiveness that create risk and uncertainty in the timber industry and the development of other economic activities that affect the opportunity costs of harvesting; both lead to a higher discount rate in the Faustmann formula. Divergences in regional institutional and political conditions affected other economic sectors in Russia and can be attributed to differences in privatization effectiveness (Selowsky and Martin,

1997; Berkowitz and DeJong, 2003; Brown et al., 2009). Previous studies have related a region's gubernatorial elections to regional socioeconomic outcomes, with regions that have more turnover in elections (potentially indicating more democratic structures), or more votes for pro-reform parties, experiencing more economic growth. In our study area, most regions in the Northwestern Federal District voted strongly in support of economic reform whereas most regions in the Central and Volga Federal Districts voted for anti-reform parties (Clem, 2006). There are also differences across the study area in enforcement of institutional reforms and control of corruption (Slinko et al., 2005). Regional-level effects in Fig. 4 pick up differences in timber harvesting attributable to these variations in risk and uncertainty.

The opportunity costs of harvesting are impacted by the development of alternative sectors of the economy and by the overall development of the forestry sector across regions. In general, the timber industry is the predominant industry in the northern regions of the study area while regions in the central and eastern parts of the study region tend to have more agricultural production. Several regions in the southern and eastern parts of the study region – notably, Moscow, Samara, and Tatarstan – are also highly industrialized. The development of these alternative economic sectors impacts the opportunity costs of timber harvesting. Additionally, regional differences in industrial capacity or equipment within the forestry sector leads to differences in the rate of return on timber harvesting. These differences may be attributable to Soviet legacies of where investments in forestry were made (Stoner-Weiss, 1997), since there has been little to no development within the timber industry since the late 1980s in Russia (Kortelainen and Kotilainen, 2003).

The statistical significance of regional-level effects supports qualitative statements that timber harvesting in Russia is influenced by political and economic factors (Torniainen, 2009). This sub-national variation in land-use outcomes has important implications outside of Russia given the policy emphasis on decentralization as a more efficient natural resource management strategy (Agrawal et al., 2008). In particular, variations in political or economic conditions at the sub-national level are likely to impact land-use changes. While the impact of these types of differences across countries on land use has been acknowledged (Lambin et al., 2001), we show that similar processes can play out within the same country. Similar results have been found for the influence of decentralized governance on deforestation in Latin America (Andersson et al., 2006; Andersson and Gibson, 2006), and our results suggest that decentralized governance also impacts extractive resource uses such as timber harvesting. There is a growing interest in the role that sub-national governance mechanisms will play in the implementation of programs under the Reducing Emissions from Deforestation and Forest Degradation (REDD) programme (Ebeling and Yasue, 2008; Clements, 2010; Sandbrook et al., 2010). Sub-national heterogeneity in political and economic conditions will be important to bear in mind in the design, implementation, and evaluation of national-level resource management strategies.

6. Conclusion

In this paper we estimate the drivers of timber harvesting in European Russia for the first fifteen years after the collapse of the Soviet Union. We find that neoclassical economic theory of timber supply explains logging, with some indication that timber harvesting responded more to market principles after 2000. This has led to a shift in where harvesting is occurring, leading to more intensive pressure on forests closer to large cities, such as Moscow city and St. Petersburg. Road density has the largest impact on harvesting in our study, all else being equal. In addition to the

impact of district-level variables on forest disturbance, we estimate regional-level effects on remaining variation in forest disturbance. Several regional differences remain even after controlling for district-level timber supply variables. These regional-level impacts are probably a result of differences across regions in the institutional or political conditions that emerged after the collapse of the Soviet Union and the rate of return from other economic activities. Our results suggest that in addition to local drivers of timber harvesting, variations in political and economic conditions across the same country can influence land-use patterns.

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