GOVERNANCE OF TIMBER HARVESTING AND FOREST CONSERVATION IN EUROPEAN RUSSIA: IDENTIFYING DRIVERS OF LEGAL AND ILLEGAL RESOURCE EXTRACTION USING SPATIAL PANEL DATA

by

Kelly Jones Wendland

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INTRODUCTION

Overview

A fundamental challenge in natural resource management is designing appropriate incentives and institutions to obtain desired economic and ecological outcomes. Traditional economic theories of the optimal allocation of natural resources make strong assumptions about property rights and zero transaction costs. Because governments define and enforce institutions, such as property rights, it is not surprising that efficient economic outcomes are exceptional, with consequences for both economic growth and environmental sustainability (North 1995; Rodrik 2003; Deacon and Mueller 2004). Understanding which institutions matter – and why – for sustainable natural resource management is thus a critical area for research. In this dissertation I use the spatial and temporal variation induced by the collapse of the Soviet Union to estimate the effect of political and economic institutions on timber harvesting and forest conservation in post-Soviet Russia.

One of the largest institutional changes in recent history started in the late 1980s in the former Soviet Union. More than twenty years after the collapse of the Soviet Union, much has been written about the transition from a command-and-control economy to a market-based economy (a small sample include: Hellman 1998; Shleifer and Treisman 2000; Herrera 2001; Frye 2001; Roland 2002; Appel 2004; Hedlund 2005; Letiche 2007; Brancato 2009; Gehlbach and Malesky 2010). One of the main lessons from this literature is that shifting political and property rights structures amidst weak institutions resulted at best in a slower-than-expected transition and at worst resulted in negative social and economic outcomes for Russia (Hellman 1998; Volkov 1999; Way 2002; Svejnar 2002; Shleifer and Treisman 2005; Ledeneva 2006). As formal institutions broke down in Russia, informal systems such as the barter economy emerged (Gaddy and Ickes 2002) and corruption and organized crime became serious obstacles to reform (Volkov 1999; Karklins 2005; Ledeneva 2006).

Forests and other natural resources were directly impacted by these changes in institutions. In the turmoil and uncertainty that followed the Soviet Union's collapse, timber harvesting declined, illegal logging increased, and protected areas became more susceptible to human threats (Colwell et al. 1997; Pryde 1998; Wells and Williams 1998; Eikeland et al. 2004; Olsson 2008; Torniainen 2009). These outcomes resulted, in part, from the rapid privatization of the timber industry and the significant decrease in funding to federal agencies like the Federal Forest Service and the Ministry of Environmental Protection and Natural Resources. Additionally, weak national and sub-national governance, strong informal rules and norms, and constantly changing legislative reforms, adversely affected implementation and enforcement of timber harvesting and conservation goals. This combination of rapid shifts in forest property rights coupled with changes in governance provide a unique opportunity to study the effect of political and economic institutions on natural resource management in Russia.

Theoretical Framework

I use a political economy framework to analyze timber harvesting and forest conservation in post-Soviet Russia. Adam Smith pioneered political economy in the 18th century, and despite it falling out of favor in the 19th century, political economy has witnessed a rapid reemergence since the 1970s (Banks and Hanushek 1995). Political economy theory is currently applied in economics and political science, and also in disciplines ranging from sociology to human geography to ecology. I use political economy to refer to the methodology of economics applied to the analysis of political behavior and institutions (Weingast and Wittman 2006). Thus, the unit of analysis (i.e., individuals or firms) and motivation (i.e., utility or profit maximization) are those traditionally used in neoclassical economics, but there is an explicit emphasis on the political nature of markets and the role of institutions (Chang 2002). Institutions in this context refer to the formal and informal rules, norms, and conventions that guide human action (North 1990).

Throughout this dissertation I use microeconomic theory on timber supply to identify what motivates a timber firm's decision to cut timber, both legally and illegally, in post-Soviet Russia. Neoclassical economic theory of timber supply provides the optimal time to cut a stand when property rights are well defined. However, a central thesis in this dissertation is that property rights were not well defined in Russia, due to weak formal institutions and strong informal norms. Political actors played a direct role in the enforcement of formal institutions and thus affected privatization effectiveness during the transition to a market economy in Russia (Berkowitz and DeJong 2003; Slinko et al. 2005; Yakovlev and Zhuravskaya 2008; Libman 2010; Granville and Leonard 2010). Strong informal norms and conventions from the Soviet period also persisted through the transition period, leading to the development of a barter system for exchange of resources. Dubbed the "virtual economy" by Gaddy and Ickes (2002), the result was that prices based on supply and demand did not immediately emerge and many enterprises that would not have stayed in business otherwise survived. Both factors affected access to and enforcement of forest property rights in Russia.

Since timber harvesting, whether legal or illegal, is ultimately a land use decision, analyzing the political economy of harvesting and forest conservation places my dissertation within the land change science literature. Land change science draws on multiple disciplines, including resource economics, remote sensing, and landscape ecology, to name just a few (Turner et al. 2007). A key aspect of land change science is that it accounts for the spatial relationship and patterns between land and decision processes. Econometric models that seek to explain human-driven land-use changes is an important component of land use science, and the pairing of remote sensing data with econometric models, as I do in my dissertation, creates a rich opportunity for research on land-use change.

Modeling the drivers of land-use change is complicated by the fact that there are both proximate factors of change – e.g., individual actions – and underlying factors of change – e.g., macroeconomic policies and national institutions (Lambin et al. 2001). One of the classic papers categorizing the types of land-use change drivers is Angelsen and Kaimowitz's 1999 meta-analysis of 140 studies of deforestation. These authors make an explicit distinction between underlying causes (the macroeconomic variables and policy instruments), immediate causes (the institutions, infrastructure, markets, and technology) and sources of deforestation (the agents of deforestation). Recently, land change science has started to focus on these larger institutional and macroeconomic processes that influence an individual's land-use decisions and has challenged researchers to include these factors into their modeling framework.

Russia provides an ideal case study to analyze the political economy of land use decisions after the collapse of the Soviet Union. By coupling microeconomic theory of timber harvesting with insight from political economy, this dissertation explicitly takes into account the impacts of underlying causes, immediate causes, and agents of land-use change in European Russia.

Background

Study Area

The Russian Federation is divided into 83 federal subjects. The most common types of federal subjects are oblasts and republics; less common federal subjects include autonomous okrugs, krais, federal cities, and one autonomous oblast. While federal subjects have equal representation in the federal government, their degree of autonomy varies according to status. Before 2005, oblasts held gubernatorial elections, but since 2005 oblasts had federally appointed governors and a locally elected legislature. Republics have greater autonomy and elect their own president, parliament and constitution. Within federal subjects political units are further divided into municipal districts, which have their own local council with elected representatives.

My dissertation focuses on timber harvesting and forest conservation in European Russia. European Russia covers about 25 percent of the landmass of Russia but more than 75 percent of the Russian population lives here. It also covers the two largest cities – Moscow and St. Petersburg – in the country. Historically, European Russia accounted for about 60 percent of all timber harvesting in the country even though it contained only 25 percent of Russia's approximately 800 million hectares of forest resources (Serebryanny and Zamotaev 2002; FAO 2010). In European Russia temperate coniferous, temperate broadleaf, and mixed forests dominate the landscape. In the extreme north of the study area are coniferous forests. As one moves south the mixed forests begin and while coniferous species such as spruce (*Picea abies*) and pine (*Pinus sylvestris*) are still found, deciduous species appear. The major deciduous species include lime (*Tilia cordata*), oak (*Quercus robur*) and birch (*Betula pendula*) in the eastern part of the study area, and beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*) in the western part of the study area. Closer to the Ural Mountains, lime-dominated forests are common (Serebryanny 2002; Hytterborn et al., 2005).

Timber Harvesting

Timber harvesting under the Soviet Union was economically inefficient due to too many authorities with unclear roles, defective administration and poor management, lack of silviculture, waste of raw material, lack of skilled labor, and inefficient forest industry (Nilsson et al. 1992). From an economic perspective, under central planning the balance between benefits and costs was skewed, leading workers to cut a larger quantity of timber than necessary. Workers then typically extracted the most valuable species and discarded the rest of the timber (Brown and Wong 1993). In addition to overharvesting at local levels, Soviet era policies led to neglect of forest regeneration and silvicultural activities in order to reduce costs (Torniainen 2009). The result was a rapid decrease in coniferous forests in Russia and an increase in deciduous forests even though most local industries are poorly equipped for processing hardwood species (Yaroshenko, personal communication).

Even before the Soviet Union fell, timber harvesting, similar to many other economic activities in Russia, collapsed. By 1991, timber harvesting was at its lowest level since before World War II. It was not until 1993 that an official forestry law was passed in independent Russia: the 1993 Principles of Forest Legislation. This legislation split forest management and industrial activities. Forest management – including silvicultural investments and allocation of use rights – remained the realm of the state, but many of the decision-making powers were decentralized to district and regional-level administrators (Krott 2000; Eikeland et al. 2004). Forest industry – including timber harvesting and processing – became the responsibility of private enterprises. Most of these private timber enterprises were remnants of state-controlled Soviet-era enterprises; however, as liberalization took effect, Russian businessmen and oligarchs, as well as foreign investors, began to move in and establish new forest enterprises. Competitive auctions were used to allocate use rights to these private enterprises. One change that did not occur to forest management, however, was the transfer of ownership rights of forests. Unlike in several other former Soviet countries, Russia chose to maintain state ownership of forestland.

From 1993 until 1997, the majority of forest management responsibilities were devolved to local forest management units (FMU). These FMU operate on a geographical scale roughly equivalent to Russian municipal districts. Forest management during this period has been characterized as corrupt and inefficient (Eikeland et al. 2004). There are two factors that contributed to these results. One factor was that FMU lacked the technical skills and training to take on these new responsibilities (Krott 2000; Torniainen et al. 2006). The other factor was that the 1993 legislation took away the primary source of funding for FMU: forest harvesting. Without supplemental budgetary resources coming from Moscow, local FMU had to rely on (illegal) harvesting and high taxes and fees on forest leases to generate revenue (Eikeland et al. 2004).

Starting in 1993, official policy was that forestland could be allocated for four purposes: 1) timber concessions for up to 49 years; 2) short-term timber leases for less than five years; 3) silvicultural leases for forest maintenance activities; and 4) personal use leases for activities such as fuelwood harvesting (Yaroshenko, personal communication). My dissertation focuses on commercial logging, or the first two user rights. Timber concessions were allocated using auctions while short-term leases were allocated on a non-competitive basis; the majority of contracts were awarded as non-competitive timber leases for less than five year (Yaroshenko, personal communication). In both cases, the responsibilities of the forest user only included timber harvesting costs, not maintenance or reforestation. While concessions and short-term leases could be allocated as early as 1993, use of these mechanisms was slow to start. By 2006, 68 percent of all economically accessible forests in Russia were non-competitively or competitively leased (Torniainen et al. 2007).

In 1997, a new Forest Code was issued. The main change was that decision-making authority was taken away from local FMU and bestowed to regional forest managers. This shift in authority helped alleviate the problem of high taxes and fees on auctions, but failed to address the perverse incentives faced by local FMU to cut timber to provide income (Torniainen et al. 2006). The central government recentralized forest authority in 2004. 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 changed responsibilities of timber enterprises, making them responsible for maintenance and reforestation costs. Torniainen et al. (2007) provides an in-depth overview of the changes in this round of the Forest Code; correspondence with experts suggest that implementation of the new legislation has been hindered by numerous legal amendments (Laestadius, personal communication). In summary, forest decision-making authority and power has shifted several times between local, regional, and federal forest sector employees since 1993 and remains in flux today.

The transition period was also a time of flux for newly privatized timber enterprises and other new actors that moved into the timber industry. Firms were adversely affected by high taxes and fees charged by the state forestry sector and by lack of enforcement of timber contracts (Yaroshenko, personal communication). For example, high auction prices in Murmansk oblast in Northwestern Russia contributed to declining rates of timber harvesting and the bankruptcy of many timber enterprises (Eikeland and Riabova 2002). During this period of uncertainty many private timber enterprises reverted to a barter system of exchange, entering the "virtual economy" that developed throughout Russia after the collapse of the Soviet Union (Gaddy and Ickes 2002). Additionally, many private firms failed once federal subsidies ended due to a lack of capacity in their new roles of procuring markets for products and finding investment capital.

The collapse of the Soviet Union also had a more indirect effect on timber firms, since the massive socioeconomic changes occurring within Russia reduced local demand for forest products (Carlsson and Olsson 1998). At the same time, market liberalization led to timber needs being increasingly served by Western competitors (Backman 1995, 1996). As a response, the timber industry in Russia became primarily export-oriented, with the majority of exports going to Finland, China, and Japan (Carlsson and Olsson 1998; Solberg et al. 2010). The combination of shifting timber demands, new international markets, new forms of governance, and privatization led to turmoil in the timber industry. The result was a significant concentration in enterprise ownership and production output. For example, in the case of pulp and paper mills, about a dozen mills account for almost 75 percent of total output (Kortelainen and Kotilainen 2003; Torniainen et al. 2006). The hurdles faced by timber firms are reflected in national forest output, which remains low, at about 23 percent of annual allowable cut utilized as of 2003, and the contribution to national gross domestic product, which is at about 3 percent (Torniainen et al. 2006).

Forest Conservation

About 12 percent of Russia's territory, or approximately 200 million hectares, is formally protected (Krever et al. 2009). The 1995 Russian Federation Law on Natural Environmental Protection designates seven types of protective forests in Russia. Four of these categories are managed at the federal level and correspond to internationally recognized, IUCN-designated categories of protected areas (Phillips 2004): strict nature reserves (zapovedniks), national parks, federal sanctuaries (zakazniks) and natural monuments. Federally protected areas cover about three percent of the country, or 54 million hectares (Krever et al. 2009). The other three types of protected areas – forest reserves, protected area forests, and forest preserves – are managed at regional and local levels (Sobolev et al. 1995; Colwell et al. 1997; Pryde 1997). I focus on three of the federally managed protected areas: zapovedniks, national parks, and federal zakazniks. (Natural monuments preserve cultural and historical sites, so are not directly related to forest conservation.)

Zapovedniks are IUCN Category I protected areas. The first zapovednik was established in Tsarist Russia (circa 1911) and the zapovednik system has been expanded and consolidated several times since then. Zapovedniks are used primarily for scientific research and nature protection, and local people were not allowed into zapovedniks during the Soviet period. Limited use access has been granted in restricted areas of zapovedniks in post-Soviet Russia (Wells and Williams 1998). National parks are a more recent land designation in Russia with the first national park created in 1983; national parks correspond to an IUCN Category II or V protected area. National parks fulfill the objective of providing recreational and environmental education opportunities to local citizens, and tend to be larger than other types of protected areas. Zakazniks are one of the oldest forms of protection in Russia and correspond to an IUCN Category IV or V protected area. There is a large network of regional zakazniks (close to 1,500), but my dissertation focuses specifically on federally-administered zakazniks. Some limited uses, such as grazing, hunting and fishing, are allowed within zakazniks.

The main organization for nature protection in Russia is the Ministry of Environmental Protection and Natural Resources (for short, Minpriroda). Since 2000, Minpriroda has managed most zapovedniks and national parks. Prior to 2000, regional branches of the Federal Forest Service managed national parks (Ostergren and Jacques 2002). Unlike the other two types of federally protected areas, zakazniks do not have a specific management organization, although the Ministry of Agriculture oversees many federal zakazniks. The management structure and objectives of federally protected areas affects funding and staffing. Zapovedniks tend to be the best funded and staffed. Funding and staffing of national parks varies considerably, and logging and other extractive activities can be permitted within national parks on a case-by-case basis. Zakazniks are typically not as well funded or staffed as other types of federally protected areas. Extractive activities can also be permitted within zakazniks.

Federal funding for protected areas has decreased precipitously since the collapse of the Soviet Union (Sobolev et al. 1995; Colwell et al. 1997; Pryde 1997). Budgets for zapovedniks are estimated to have decreased by as much as 90 percent of 1989 levels (Wells and Williams 1998). In addition to the effects that decreased federal funding and staffing have, ministerial confusion over management responsibilities within the central government also led to increased threats within protected areas (Sobolev et al. 1995; Colwell et al. 1997; Pryde 1997; Wells and Williams 1998). The abolishment in 2000 of Russia's official environmental watchdog, the State Committee on the

Environment, was seen as some as a direct threat to preservation of Russia's forests (Ostergren and Jacques 2002). On the other hand, one positive trend for protected areas governance since transition is the increasing presence of non-governmental organizations (NGOs) in Russia. NGOs help monitor protected areas and provide environmental education to local citizens (Pryde 1997; Wells and Williams 1998).

While budgets for protected areas have been shrinking, the number of protected areas has grown since transition: between 1994 and 2008 Russia established 12 new zapovedniks and 12 new national parks (Wells and Williams 1998; Krever et al. 2009). Part of this was motivated by the privatization of land in 1991, and thus urgency on the part of the state to set aside land while the opportunity existed (Pryde 1997). Other motivations include status seeking by regional administrators, and in other cases, a genuine interest in biological diversity in places where individuals or scientists were able to get large tracts of land protected (Dubinin, personal communication). Federally protected areas are distributed across the Russian Federation, and protected areas in European Russia tend to be smaller in size than those in Siberia due to higher population density (Colwell et al. 1997). This proximity to people and industry, in combination with the lack of funding, enforcement, and weak state governance, creates a multitude of opportunities for illegal exploitation within conservation areas in European Russia (Sobolev et al. 1995; Pryde 1997).

A 2009 GAP analysis for conservation planning recommends that as many as 508 new terrestrial areas receive protected areas status to fully conserve biological diversity in Russia (Krever et al. 2009). About half of these proposed areas require modifying the current status or size of an existing protected area (216), but an additional 267 would be newly created protected areas. Federal zakazniks make up the majority of the recommended changes to parks, with 199 new zakazniks recommended; an additional 134 zapovedniks and 70 national parks are also recommended.

Chapter Summaries

Given significant changes to institutional arrangements over the last 20 years in European Russia, my dissertation analyzes timber harvesting and forest conservation outcomes and identifies the determinants of these land use decisions.

In **Chapter 1** I analyze the drivers of timber harvesting in 32 regions in European Russia between 1990 and 2005. This research provides the first quantitative analysis of how district- and regional-level factors affected forest disturbance after the collapse of the Soviet Union. I use the Faustmann formula for a single-rotation of harvesting to inform the econometric model in this paper, and estimate it using a panel data multilevel model. Data on forest disturbance come from two secondary remote sensing analyses, and independent variables come from spatial datasets. I find that timber harvesting in Russia followed neoclassical economic theory, with more harvesting occurring where net prices are lower – measured as biophysical access and transportation costs – and timber supply is higher – measured as total forest area. Where harvesting occurred shifted over these 15 years, with more harvesting occurring closer to urban areas after 2000. In addition to these district variables, I estimate the effect that regions had on timber harvesting and find that most regions had a statistically significant effect even after controlling for net prices and timber supply. Regional differences in political institutions, economic development, and capacity within the forestry sector would affect the discount rate of timber harvesting. This chapter contributes to knowledge about land use changes in Russia after the Soviet Union and more broadly, shows that in addition to local biophysical and economic conditions, sub-national differences in political institutions and macroeconomic conditions can significantly impact land use outcomes.

In **Chapter 2** I estimate the impact of regional governance on timber harvesting in European Russia. This builds directly on findings in Chapter 1 that regional-level factors affected harvesting. A priori, the effect of differences in regional governance on resource extraction is theoretically ambiguous. This is because the risk and uncertainty created by poor governance has two counteracting effects on resource extraction: it raises the marginal net benefits of cutting timber today, leading to an increase in extraction, and it raises the opportunity costs of capital, leading to decreased pressure on the resource. To empirically test the effect of regional governance on logging I estimate a panel data fixed-effects model using district-level variables from Chapter 1 and a regional measure of governance published by the Carnegie Center Moscow. I find a statistically significant and non-monotonic effect of governance on logging in Russia. This finding is robust to alternative specifications and when controlling for the effect of economic growth on resource extraction. Graphing the relationship between governance and the number and area of timber leases suggests that governance directly affected access to forest property rights in Russia. This chapter provides within-country evidence of a causal relationship between governance and logging that differs from the relationship between governance and deforestation. My findings have important environmental implications for policy prescriptions that suggest that improving governance will decrease pressure on forests.

In **Chapter 3** I evaluate the effectiveness of protected areas on forest conservation in post-Soviet Russia. The number of federally protected areas increased rapidly right before and after the collapse of the Soviet Union, at the same time budgets for parks were decreasing and pressures from illegal logging were intensifying. To measure forest disturbance within and outside of parks, I use pixel-level data from eight Landsat footprints in Central Russia (Baumann et al., *in preparation*). These data are available for 5-year intervals between 1985 and 2010, which allows me to measure park effectiveness before, during and after the collapse of the Soviet Union. To account for the non-random placement of protected areas I use a combination of methods. First, I measure impact using nonparametric propensity score and distance-based matching metrics. Second, I combine matching and regression analysis to provide a more robust estimate of park effectiveness. This includes using panel regression to control for time-invariant unobservables. I find that strict protected areas prevented logging after 1995, but had no effect on logging right before or after the collapse. Other types of federally protected areas had no effect on preventing logging compared to observations with similar characteristics. This chapter provides policy lessons for forest conservation in Russia given calls to expand the protected area network, and more broadly, showing that biodiversity conservation can be adversely affected in times of non-violent political and socioeconomic change. It also adds to a growing literature on best practices for measuring the causal impacts of conservation interventions.

Significance

In my dissertation, I identify the impacts that underlying causes, immediate causes, and agents of change had on timber harvesting and forest conservation in post-Soviet Russia by combining remote sensing data with econometric analyses of the political and economic drivers of land use. In doing so, I make several theoretical and methodological contributions to the political economy and land change science literature, and to the regional literature on Russia.

The overall theoretical contribution of my dissertation is the finding that spatial and temporal differences in implementing and enforcing institutions – a result of divergence in governance across Russian regions – have a direct effect on land use outcomes. Spatial and temporal variations in political and economic conditions after the fall of the Soviet Union affected forest property rights, leading to inefficient levels of timber production and illegal harvesting in conservation areas. Chapter 1 illustrates the magnitude of this influence after controlling for more disaggregated biophysical and economic determinants of timber supply. This chapter highlights the importance of controlling for the underlying and immediate causes of land use changes within the same country. Controlling for underlying and immediate causes is a concept that has been emphasized in cross-country studies (Lambin et al. 2001) but has received relatively little attention for within-country analysis.

In Chapter 2 I show that sub-national governance – measured as the type of political institutions and the capacity of the state to implement and enforce institutions – is directly related to timber harvesting. This work contributes to a small, but expanding body of literature on the relationship between governance and resource extraction (Bohn and Deacon 2004; Ferreira and Vincent 2010). In particular, it adds to the conceptualization of the relationship between governance and capital-intensive timber harvesting versus the relationship between governance and deforestation.

Chapter 3 emphasizes the importance of temporal differences, showing the impact that large non-violent political and socioeconomic shifts can have on land use outcomes. This chapter also accounts for spatial differences in institutions by controlling for regional-level unobservables in estimating the effect of conservation interventions. Together, my three chapters emphasize that the combination of formal and informal institutions within the same country can lead to very heterogeneous outcomes, affecting both economic productivity and provision of ecosystem services from the land.

These theoretical contributions are important for forest management within Russia but are also relevant more broadly. There is a long-standing interest in decentralizing resource management (Colfer and Capistrano 2005; Bartley et al. 2008; Agrawal et al. 2008). However, my dissertation shows that without proper supporting mechanisms – most of which are lacking in transitional and developing countries – decentralization will not necessarily lead to more efficient outcomes, and in some cases will lead to quite inefficient and inequitable outcomes. The lack of national-level supporting mechanisms for decentralized governance in post-Soviet Russia has been well documented, both within and outside of the forestry sector (Carlsson and Olsson 1998; Frye 2000; Hanson and Bradshaw 2000; Eikeland et al. 2004). Similar variations are found across other countries and at the community level. While other literature suggests that cross-country differences in political and property-rights institutions can affect economic growth and environmental sustainability, my work provides important evidence that similar results can be found within the same country. Regarding temporal changes in land use following large political and socioeconomic shifts, this research illustrates how lack of supporting mechanisms can lead to adverse impacts on biodiversity conservation. This suggests that outside support and assistance might be required during times of transition to ensure biodiversity and ecosystem conservation goals are met.

These heterogeneous impacts have important implications for the design, implementation, and effectiveness of national-level policies for natural resource management and economic growth. In Russia, forest legislation and annual allowable cut of the timber resource are decided in Moscow; however, regional and local authorities are responsible for implementation and enforcement of rules, and thus directly impact the rents that timber generates for the country. As Russia struggles to implement the 2007 Forest Code, which makes significant changes to forest property rights, it will be these same political actors that influence the economic productivity of the timber industry. Similarly, enforcement of conservation areas varies according to the resources and incentives faced by park managers. With hundreds of new protected areas proposed for Russia, and no plans for increased funding or changes to incentives for managers, it is questionable how effective these areas will be at conserving biodiversity. At the global level, the incentives that political actors face will have major consequences for the implementation of market-based mechanisms such as payments for ecosystem services under the United Nation's Reducing Emissions from Deforestation and Forest Degradation (REDD) programme (Ebeling and Yassue 2008; Clements 2010; Sandbrook et al. 2010).

Methodologically, my dissertation also makes several important contributions to the political economy and land use science literature. In Chapter 1 a multilevel model is used to control for spatial autocorrelation using a nested, two-stage structure. Accounting for spatial dependence based on fixed neighborhood effects has only recently emerged in spatial econometrics (Anselin 2002), and I show that it can be a useful strategy to control for spatial correlation in clustered data. While other land use change studies have used multilevel models (for example: Hoshino 2001, Pan and Bilsborrow 2005, Vance and Iovanna 2006, and Overmars and Verburg 2006), none verified that correlation across clusters did not bias results as I do in this chapter by testing model residuals using Moran's I. Chapter 2 is unique in its use of spatially- and temporally-variant within-country data to directly estimate the effect of institutions – in this case political institutions and state capacity and effectiveness – on resource use. Previous studies have relied on cross-country data, and national statistics (for example: Bohn and Deacon 2004; Ferreira and Vincent 2010). In addition to its more robust identification strategy, Chapter 2 uses several econometric techniques to address endogeneity issues between institutions and economic growth, a problem that plagues many institutional analyses. The chapter uses two instrumental variables that to the best of my knowledge have not been used elsewhere in the literature: first, a measure of productivity to instrument for economic growth, and second, a measure of expenditures on alcohol.

Chapter 3 addresses the selection bias problem inherent in evaluating conservation interventions. It uses nonparametric matching, which has been shown to correct for bias from observables but has only recently been adopted in the conservation evaluation literature (for example: Andam et al. 2008; Joppa and Pfaff 2010). Additionally, this chapter also uses post-matching panel regression, which controls for time-invariant unobservables, to measure park effectiveness. This controls for hidden bias that can be present when using matching alone, and has not been used elsewhere to measure protected area effectiveness. By combining these two methods, this chapter illustrates a "best practice" for causal impact evaluation.

These methods are relevant for any study estimating the impact of institutions and the effect of conservation interventions. Endogeneity problems plague empirical understanding of the relationship between institutions and growth (Acemoglu et al. 2005; Rodrick 2003). Within-country data has several advantages over cross-country data for estimating the causal effect of institutions on economic growth or resource management since national-level institutional differences are minimized. The importance of this has been recognized in post-Soviet countries, where countries had very different cultural and institutional beginnings (Ghelbach and Malesky 2010). When there is substantial spatial and temporal variation within a single country, as shown in Chapter 2 of my dissertation, the advantages for estimating causal relationships are even greater. Additionally, the instrumental variables used in this study have broader relevance for research on economic growth and land use change. Economic growth is often instrumented using climate or geographic variables (Acemoglu et al. 2005), but this strategy does not work when the outcome variable is dependent on climate or geography, or when it varies over time. The instrumental variables used in my dissertation – productivity measures and alcohol expenditures – could be used in future land change research.

Interest in measuring the impact of conservation interventions is growing rapidly across the globe (Ferraro and Pattanayak 2006; Kapos et al. 2008; Ferraro 2009). A common strategy has been to use nonparametric matching methods to control for observable differences (Andam et al. 2008; Joppa and Pfaff 2010). However, combining matching with panel regression models, as I do in Chapter 3 of my dissertation, can provide a more robust causal estimate of effectiveness since it controls for hidden bias. Results from Chapter 3 show that especially during times of transition, when unobservables are more likely to be present, hidden bias can lead to incorrect estimates of protected area effectiveness. This has important implications for programs like REDD which are based on the assumption that the impact of conservation interventions on land use can be precisely estimated.

In summary, my dissertation shows that political and economic factors matter for land use decisions; both affect implementation and effectiveness of natural resource policies. Since political and economic conditions vary across both space and time, using spatially-explicit panel data models provides a more robust strategy for estimating the drivers of land use change than previous analyses that relied on cross-sectional samples or nationally-reported statistics. Especially when governance and institutions are determinants of land use outcomes, the combination of remote sensing data with panel data is one way to mitigate biases associated with measurement error from national statistics and unobservables related to the emergence of particular governance and institutional regimes.

The transition process in Russia and other former Soviet countries led to significant institutional changes, several with negative consequences for sustainable natural resource management. If some of the lessons being learned through this process are incorporated into the design and implementation of future natural resource policies within Russia and beyond, then this "grand experiment" will have served some good for natural resource management.

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CHAPTER 1: Regional- and district-level drivers of timber harvesting in European Russia after the collapse of the Soviet Union

Coauthors: David J. Lewis, Jennifer Alix-Garcia, Mutlu Ozdogan, Matthias Baumann, Volker C. Radeloff

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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 have been no quantitative assessments 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 and 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 – had 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.

Keywords: econometrics, forest disturbance, land-use change, remote sensing, Russia

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., *in press*). 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 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.

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 1993). 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 prices[1] is:

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

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:

$$MNB_{T,k,cleared}\left(P(T), \frac{dP(T)}{dT}, X(T), \frac{dX(T)}{dT}, \delta\right) = \frac{dP(T)}{dT}X(T) + \frac{dX(T)}{dT}P(T) - \delta P(T)X(T), \quad (2)$$

where $MNB_{T,k,cleared}$ is the marginal *net* benefit of clearing a stand *k* in time *T*.

[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.

The parameters *P(T)*, *X(T)*, *T* and δ in Equation 2 would impact a timber firm's decision to cut a stand when faced with market conditions. Net prices, *P(T)*, would 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 Equation 2 for δ:

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

Equation 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; where alternative activities yield higher rates of return, we would expect to see less timber harvesting.

Study Area and Data

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 (Figure 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 (Figure 2). The study area covers about 3 million km^2 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 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 (Figure 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.

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 (Figure 1). This gives a total sample size of 1,489 observations. The average value of forest disturbance over the entire study period was 6.4 km^2 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 recreated 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 1,921 km^2.

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 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 m^2); road data were generated from topographic maps of Russia produced around the collapse of the Soviet Union. Distance was calculated from the center of each district to either Moscow city or St. Petersburg, depending on which was 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 below) to estimate the regional-level influence on timber harvesting.

Calculation

Estimating district-level drivers of forest disturbance

We construct a reduced-form empirical equation using Equation 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:

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

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 Equation 4 as:

$$\varphi_{0j} = \delta_{00} + \mu_{0j}. \quad (5)$$

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:

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

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 an alternative strategy in correcting 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, and 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 cannot be rejected in model residuals, then we have confidence that the nested structure of the multilevel model accounted for spatial autocorrelation.

To estimate Equation 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 the results section, 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 Equation 6: as presented above and with interactions between all parameters and the time dummy variable. The former specification assumes that covariates had 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 had different effects over these two periods.

In addition, we parameterize the two different specifications of Equation 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 2000-2005 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 Equation 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

[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.

for the multilevel model). Rabe-Hesketh and Skrondal (2008, p.58) give the formula for the intraclass correlation as:

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

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 Equation 6 with covariates, the formula for R^2 is given in Rabe-Hesketh and Skrondal (2008, p.102) as:

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

Estimating regional-level effects on forest disturbance

While regions are treated as random effects in Equation 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 Equation 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 Equation 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 had on the remaining variation in timber harvesting, after controlling for district-level covariates and the district-level random effect.

Results and Discussion

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. From 1990 to 2005, a total of about 73,400 km^2 of forest were cut. With about 1.3 million km^2 of forest in the study area, this equates to disturbance in about 5.3 percent of the forest. From 1990-2000 the total forest area cut was about 51,500 km^2 with an average annual percent change of 0.25; total forest disturbance from 2000-2005 was about 21,900 km^2 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 km^2 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 (Figure 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.

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 (Figure 2). From 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 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 was 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, Figure 3 suggests that where timber harvesting occurred shifted between these two time periods.

Turning to the econometric estimates, we first consider estimates from the null model (Table 2). Using Equation 6, 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. 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.

Turning to 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 Equation 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, 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

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[3] Similar econometric results were found using the average value and standard deviation of slope. Additionally, we explored adding elevation to the model, but slope and elevation were 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.

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 R^2 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, we find that 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 was more forest cover, b) there was more valuable timber (i.e., evergreen species), and c) the costs of harvesting were lower (i.e., road density was higher and slope was less variable). The only effect that was counter to neoclassical economic theory was the sign on distance to markets: based on the theory, we would expect that districts closer to markets would 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 Figure 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.

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 (Figure 4). Eleven regions had a positive effect on forest disturbance and 22 regions had 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 (Figure 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 Figure 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 impacted land-use changes.

Some possible reasons why we might expect to find significant regional-level effects were discussed in the theory section. These included regional differences in privatization effectiveness that would create risk and uncertainty in the timber industry and the development of other economic activities that would affect the opportunity costs of harvesting; both would increase the discount rate in the Faustmann formula. Divergences in regional institutional and political conditions would lead to differences in risk and uncertainty; these regional variations 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 had 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 Figure 4 would pick up differences in timber harvesting attributable to these variations in risk and uncertainty.

The opportunity costs of harvesting would be 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 would impact the opportunity costs of timber harvesting. Additionally, regional differences in industrial capacity or equipment within the forestry sector would lead 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).

In general, the statistical significance of regional-level effects supports qualitative statements that timber harvesting in Russia was 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). Our results suggest that, even after controlling for district-level determinants of land use, 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), our study shows 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). 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 Yassue 2008; Clements 2010; Sandbrook et al. 2010). Our findings suggest that 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.

Conclusion

In this paper we estimate the drivers of forest disturbance in European Russia for the first fifteen years after the collapse of the Soviet Union. We find that forest disturbance is explained by neoclassical economic theory of timber supply, 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. We find that road density has the largest impact on where harvesting occurred, 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 persisted 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. These 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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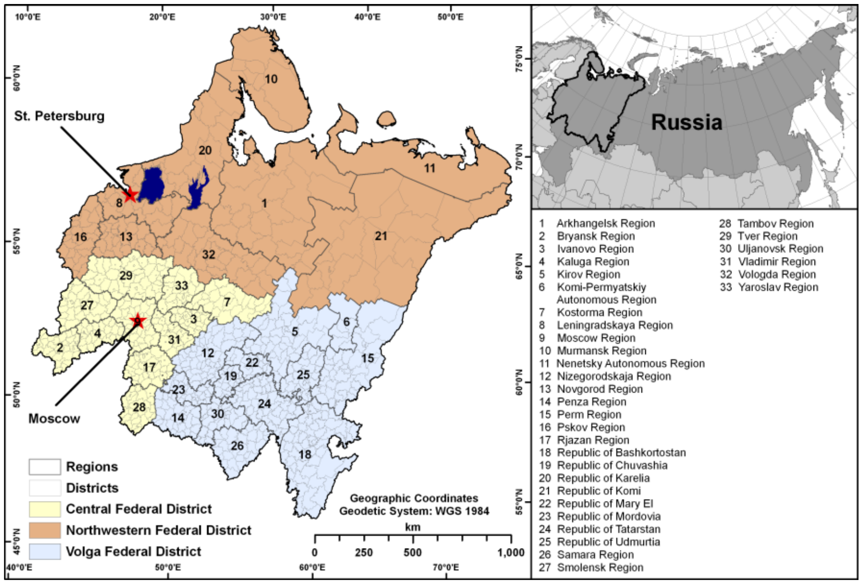

Figure 1. Map of political units in our study area in European Russia

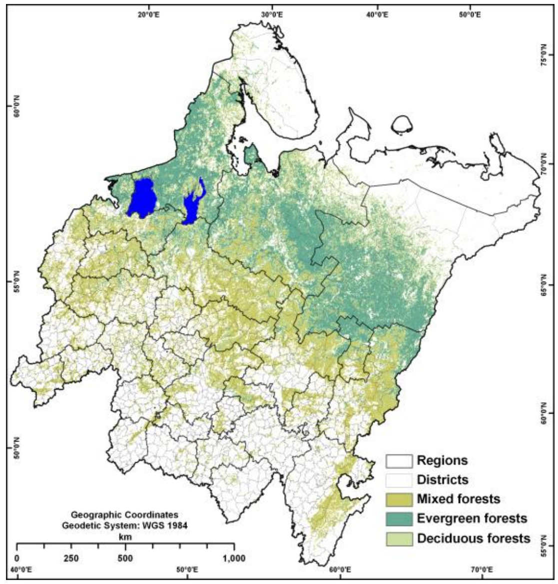

Figure 2. Map of forest types in study area in European Russia

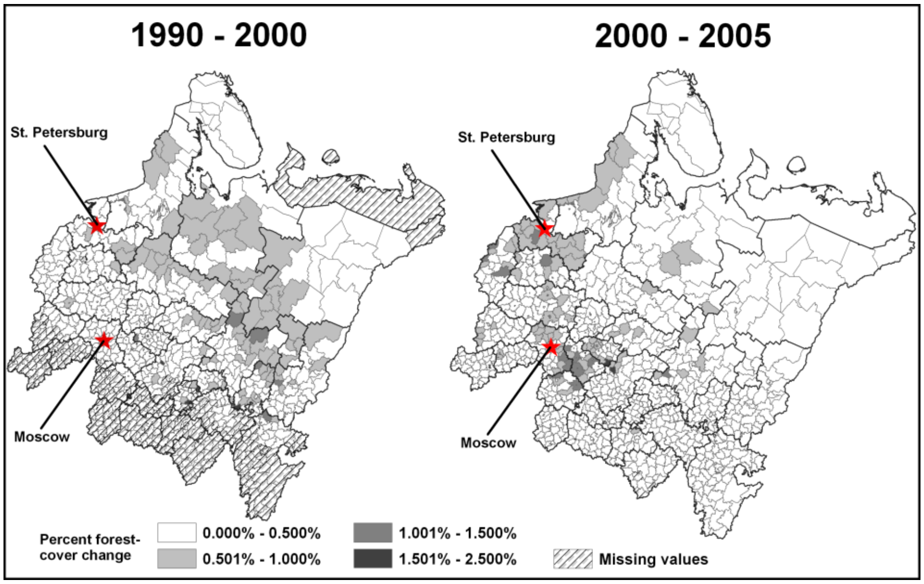

Figure 3. Map of annualized percent change in forest cover in study area for 1990-2000 and 2000-2005. Annualized area (km2) of forest disturbance is normalized by total forest area (km2) in that district

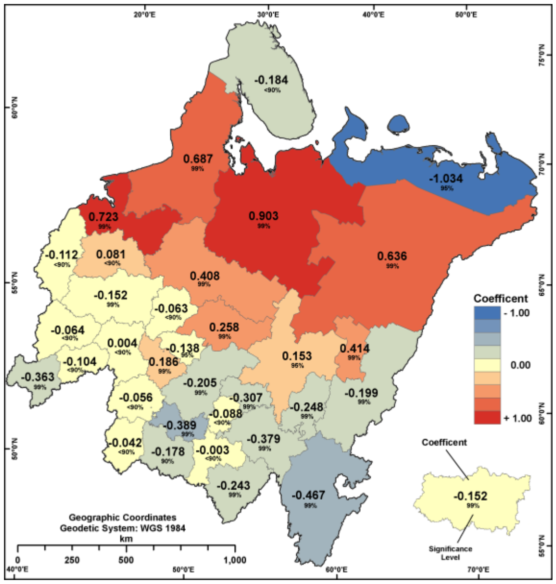

Figure 4. Map of magnitude and significance of regional effects on forest disturbance

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

Panel A: Description and data source

Variable	Description	Data source
Forest disturbance	Area (km²) 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 (km²) 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 (meters) in a district divided by area of that district (m²); 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

Panel B: Summary statistics

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Forest disturbance (km²)	1,489	6.40	15.32	0	215.73
Forest area (km²)	1,489	1,921.04	3,719.96	0	33,957.32
Evergreen (%)	1,489	47	36	0	100
Slope (degrees)	1,489	0.74	0.57	0	5.78
Road density (m/m²)	1,489	0.01	0.03	0	0.40

Market (km)	1,489	532.54	330.41	0	1,837.00
Time dummy	1,489	0.5	0.5	0	1
Panel C: Log-transformed summary statistics					
Forest disturbance	1,489	1.18	1.11	0	5.38
Forest area	1,489	6.32	1.94	0	10.43
Evergreen	1,489	0.36	0.25	0	0.69
Slope	1,489	0.52	0.24	0	1.91
Road density	1,489	0.01	0.03	0	0.34
Market	1,489	6.03	0.82	0	7.52

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

Variable Name	Null model	Specification 1		Specification 2	
	Sample 1	**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**
	Coefficient (Std Error)	Coefficient (Std Error)	Coefficient (Std Error)	Coefficient (Std Error)	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	1,489	1,489	1,414	1,489	1,414

Number of districts	890	890	850	890	850
Number of regions	33	33	32	33	32

*** p<0.01, ** p<0.05, * p<0.1

[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.

CHAPTER 2: The effect of decentralized governance on logging rates in European Russia

Coauthors: David J. Lewis, Jennifer Alix-Garcia

Status: In preparation for *Environmental and Resource Economics*

Abstract

In this paper we test the impact of decentralized governance on timber harvesting by exploiting within-country heterogeneity in Russia after the collapse of the Soviet Union. Using a fixed-effects model we find a statistically significant and non-monotonic effect of governance on the area of timber harvested. These results are robust to alternative specifications and when instrumenting for economic growth. Findings from this analysis provide additional evidence of a causal relationship between governance and natural resource extraction that differs from the effect of governance on deforestation. One mechanism through which governance impacted timber firms in Russia is through access to forest property rights.

Keywords: decentralization, forests, governance, logging, property rights, Russia

Introduction

In this paper we examine the role of sub-national governance on logging rates in European Russia from 1990 to 2005. The role of governance in the creation of economic wealth and development, as well as in sustainable resource management, has received considerable attention in the last decade (Banerjee 1997; Kaufman and Kraay 2002; Deacon and Mueller 2004; Acemoglu et al. 2005; Robinson et al. 2006; Kaufmann et al. 2006; Baland et al. 2010). Governance is part of a more general literature on the political economy of institutions and development. In a review of governance and growth, Baland et al. (2010) categorize measurements of governance as two types: those measuring political institutions and those measuring state capacity and effectiveness. Despite attention, the causal relationship between governance and growth, and in particular, governance and natural resource extraction, is not always clear (Deacon and Mueller 2004; Barrett et al. 2005; Ferreira and Vincent 2010; Baland et al. 2010). In this paper we estimate the impact of governance on logging rates within 31 administrative regions in European Russia. The within-country approach minimizes many of the omitted variable problems that plague cross-country studies. In addition, within-country effects of governance on resource extraction can provide important insight on the effectiveness of decentralization given increasing global trends in divesting power to sub-national and community levels (Casson and Obidzinksi 2002; Agrawal et al. 2008; Bartley et al. 2008).

One channel through which governance can impact natural resource extraction is through its effect on the discount rate. Whether the effect on the discount rate will increase or decrease natural resource extraction depends on the capital-intensity of the activity (Farzin 1984). When there are high capital costs, as with commercial logging, an increase in the discount rate has two distinct and countervailing effects: it raises the marginal net benefits of cutting timber today, leading to an increase in extraction, and it raises the opportunity costs of capital, leading to decreased pressure on the resource. The overall impact is theoretically ambiguous. Bohn and Deacon (2000) use cross-country data to examine the impact of an index of investment risk, which includes measures of political stability and regime, on petroleum extraction. They find that lower investment risk is associated with increased petroleum extraction. Ferreira and Vincent (2010) estimate the impact of an index of government stability and government integrity on commercial logging across developing countries. They find that governance has a non-monotonic impact on logging: a marginal increase in governance leads to more extraction in countries with weak governance, but decreases extraction in countries with strong governance. These findings contrast with previous estimates of the relationship between governance and deforestation, where better governance is correlated with less deforestation (Bohn and Deacon 2000; Barbier et al. 2005). This difference in outcomes has important environmental implications and suggests that the type and intensity of natural resource use might change with different types of governance.

To identify the effects of governance on logging, we use the spatial and temporal variation in governance across Russia induced by the collapse of the Soviet Union (Stoner-Weiss 1997; Hanson and Bradshaw 2000). Political and economic authority was transferred toward administrative regions as early as 1985 in Russia; these transfers of power were formalized in 1991 when regions began electing their own governors and ended in 2004 with the recentralization of gubernatorial elections. Divergences in legal and political institutions between 1991 and 2004 left administrative regions in Russia with an array of political structures ranging from pluralist democracies to autocracies to "warlordism" (Libman 2010). The causes of these divergences in governance are complex: ethnicity, geographical location and economic legacies from the Soviet period are a few of the factors related to differences in social and economic outcomes across regions (Stoner-Weiss 1997; Hanson and Bradshaw 2000; Ickes and Offer 2006). These divergences impacted regional privatization effectiveness, firm productivity and economic growth (Berkowitz and DeJong 2003; Slinko et al.

2005; Yakovlev and Zhuravskaya 2008; Libman 2010; Granville and Leonard 2010). To measure regional-level governance in European Russia we use indicators published by the Carnegie Center Moscow that relate to political institutions and state capacity and effectiveness (Petrov 2005). The Carnegie Center Moscow published rankings of regional governance for 1991-2001 and 2001-2005; we create an average governance measure for each region that varies across space and time.

Similar changes occurred within the forestry sector. While forests remained state owned, Russia decentralized forest management, privatized the timber industry, and transitioned to a system of short- and long-term timber leases. Russia released official forestry legislation in 1993, 1997, 2004 and 2007 but did not make any changes to the content of property rights until 2007 when it changed the duration of forest leases and responsibilities of lessees. Thus, we are confident that the legal content of forest property rights is uniform across our sample and study period, something that is difficult to control for in a cross-country analysis. To measure logging we use data from a 1990-2000 and a 2000-2005 remote sensing classification of forest disturbances. Using remote sensing data allows us to mitigate concerns about measurement error, whether from human error or from "illegal" logging, which affects national forestry statistics in Russia (World Bank 2004; Ottitsch et al. 2005). While many of the factors that might influence timber supply (e.g., exchange rates, trade barriers, etc.) will be similar within Russia, we control for biophysical and economic determinants of timber supply expected to vary across our sample. We aggregate forest disturbance and measures of the biophysical and economic determinants of timber supply to district boundaries[4]. In total, there are 877 districts within our study area, nested within 31 regions.

[4] Regions are the first degree and districts the second degree of administrative division beyond the national level in Russia. Regions were the level of decentralization of political power in Russia and are therefore the level where governance is measured. We measure forest disturbance at the district level to more precisely control for biophysical and economic drivers that vary within regions.

To test the impact of governance on forest disturbance we estimate a fixed-effects model of timber supply. Regional fixed effects control for time-invariant unobservables at the regional level that might be correlated with governance and logging; time fixed effects control for changes over time, such as global timber prices, that would affect all regions. The primary results confirm a statistically significant effect of governance on logging in European Russia, even controlling for regional economic growth. In most cases the effect of governance on logging is non-monotonic: a marginal increase in governance at low levels of governance increases harvesting and a marginal increase in governance at high levels decreases harvesting. This relationship mirrors that found in Ferreira and Vincent's (2010) cross-country analysis of governance and logging. These results are robust to a variety of tests intended to address potential simultaneity bias between economic growth and logging. Additionally, we find no effect of governance on logging when we falsify the governance measure, providing evidence that these results are not spurious. Finally, we explore possible mechanisms through which governance impacts logging by testing the effect of indicators specific to political institutions and state capacity and effectiveness on harvesting. State capacity and effectiveness has a statistically significant and monotonic effect on logging; political institutions have a weakly significant and non-monotonic effect. Combined with data showing a strong correlation between better governance and area of timberland leased and number of timber contracts, these results suggest that governance affected access to forest property rights in Russia.

Conceptual Model

Timber harvesting is the primary driver of forest disturbance in European Russia (Potapov et al. 2011). Given decreasing domestic demand for timber associated with the rapid socioeconomic changes after the collapse of the Soviet Union, timber exports constitute a considerable portion of total firm output. Industrial logging is capital-intensive in Russia: it requires heavy machinery, most of which is outdated and badly worn, and high transportation costs (Carlsson and Olsson 1998). During the Soviet period, decision-makers did not internalize these costs of production (Brown and Wong 1993), but after Russia liberalized markets, private timber firms were constrained by these costs (Pappila 1999; Kortelainen and Kotilainen 2003). In addition to costs of production, the profitability of timber harvesting was affected by "illegal" fees and bribes placed on timber contracts by the state forestry sector (Krott et al. 2000; Eikeland et al. 2004) and by weak legal capacity and enforcement of property rights by the state (Torniainen and Saastamoinen 2007).

We conceptualize a firm's decision to cut timber as the decision to maximize profits from a stand under a single rotation, i.e., the Faustmann formula, which can be written as:

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

where π is profits; *P(T)* are time-varying net prices; *X(T)* is timber stock at time *T*; and δ is the discount rate. Decision-makers maximized profits from a single rotation because leases were for a maximum of 49 years and the majority of leases were for 5 years or less during the study period (Torniainen 2009). For a timber stand, *k*, the optimal rotation period is found by taking the first order condition with respect to *T*, which gives:

$$MNB_{T,k,cleared}\left(P(T), \frac{dP(T)}{dT}, X(T), \frac{dX(T)}{dT}, \delta\right) = \frac{dP(T)}{dT}X(T) + \frac{dX(T)}{dT}P(T) - \delta P(T)X(T), \quad (2)$$

where $MNB_{T,k,cleared}$ is the marginal *net* benefit of clearing a stand *k* in time *T*. The parameters *P(T)*, *X(T)*, *T* and δ in Equation 2 would impact a timber firm's decision to cut a stand when faced with market conditions. The importance of the discount rate in determining the optimal time to cut timber can be found by solving Equation 2 for δ:

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

Thus, the optimal time to cut a stand is when the rate of return from the stand, which changes over time, equals the rate of return elsewhere in the economy. Risk and uncertainty increase the discount rate; governance, defined as the type and stability of political institutions and the capacity of the state to enforce rules and regulations, certainly affects risk and uncertainty. Farzin (1984) shows that when there are high capital costs, the typical assumption in resource economics that an increase in the discount rate on exhaustible resources leads to faster depletion does not hold. Instead, there are two distinct and countervailing effects. The first effect is the one traditionally considered in the literature: the depletion effect, where an increase in the discount rate increases the marginal net benefits of harvesting timber today. This leads to an immediate increase in extraction. Weak enforcement of forest property rights by the state would be one mechanism through which governance could directly lead to a depletion effect in Russia.

The second effect is that the higher discount rate increases the unit costs of extraction, or the opportunity costs of capital, which decreases net profits and therefore discourages extraction. This is known as the investment effect, since firms would want to invest their capital elsewhere. The high "illegal" fees and bribes placed on timber contracts by the state would be one pathway through which poor governance could directly raise costs of extraction and lead to an investment effect in Russia. The overall impact of these two effects on resource extraction is theoretically ambiguous; Farzin (1984) demonstrates that for two different stock sizes it is the investment effect that dominates. Bohn and Deacon (2000) also find that the investment effect dominates the depletion effect for petroleum extraction and Ferreira and Vincent (2010) find a non-monotonic effect of governance on logging in their cross-country analysis, where the investment effect dominates at low values of governance but not at high values of governance. In sum, the question of whether improvements in governance increase or decrease harvesting is an empirical question.

Study Area and Data

Study Area

The total study area covers about 3 million km^2 in European Russia, of which approximately 42 percent is forested. Thirty-two regions are covered by the study area (Figure 5). However, national statistics are not available for one region[5]; thus, for all specifications the sample size is 31 regions and 877 districts.

Timber Harvesting

Remote sensing classifications of the total area (km^2) converted from forest to non-forest between 1990-2000 and 2000-2005 are used to measure commercial logging.[6] Measures for 1990-2000 come from an unpublished analysis by Greenpeace-Russia (Yaroshenko et al. *unpublished*) and cover 26 regions and 599 districts. The 2000-2005 measure comes from Potapov et al. (2011) and is available to the public on the Boreal Forest Monitoring project website. These data cover all 31 regions. We annualize these measures to ease interpretation of regression coefficients. In Table 3, data on logging are summarized at a district level: average area logged is about six km^2 per year.

[5] Regional statistics are not available for Komi-Permyatskiy Autonomous Region; this region was merged with Perm Region in 2005.

[6] While the remote sensing analyses are for two discrete time periods, some variation and thus overlap in the satellite images is to be expected. For example, the 2000 to 2005 change product uses images from 1999 to 2002 to measure 2000 forest cover and images from 2003 to 2005 to measure 2005 forest cover (Boreal Forest Monitoring project website). These differences could lead to over or under estimation in the area of forest disturbance; the time dummy used in the regression models controls for these differences.

Governance

Regional-level governance is measured using indicators published by the Carnegie Center Moscow for 1991-2001 and 2001-2005 (Petrov 2005). Governance measures from 1991-2001 are used to represent the period of forest disturbance in 1990-2000 and measures from 2001-2005 are used to represent the period of forest disturbance in 2000-2005. The indicators include: civil society, free and fair elections, political stability, competition in elections, independence of media, government transparency, balance of powers, and quality of district governments (see Table 4 for definitions). The Carnegie Center Moscow ranked each indicator on a five-point scale, where five is the highest possible score. So, as an example, a score of five for civil society represents a regional government with more public participation than a region that scored one. To reduce measurement error, the average value of the eight indicators is used; this value varies across space and time with a range of 1.5 to 4.3 and a mean of three (Table 3).

To establish validity of the average governance score for a region we compare it to an assessment of the investment potential of Russian regions. Measurements of governance are by nature subjective and even widely used measures are open to criticism (for example, see: Kaufmann et al. 2007; Kaufmann et al. 2009; Kaufmann et al. 2010). Expert RA Rating Agency is part of an international group of publishing and research companies known as Expert Group and has published rankings of investment potential within Russian regions since 1995. These rankings include aspects of investment potential that go beyond governance: they also rate potential based on economic, social, and biophysical factors. Despite this broader definition, a strong correlation between Expert RA rankings and the Carnegie Center Moscow measure provides additional confidence in the governance measure (Figure 6). The scatter plot between governance – where higher indicates better governance – and investment potential – where higher indicates greater investment potential – is strong, with two regional outliers. Both outliers rank poorly in governance because elections are not free and fair and there is little public participation in government, but score high in investment potential due to heavy Soviet period industrialization.

Control Variables

To correctly identify the effect of governance on logging in Equation 2 we also need to control for P, X, T, and δ. Data descriptions and summary statistics for these covariates are found in Table 3. Data on net prices, P, are not directly observed[7], but measures of the type of timber, accessibility of timber stands, and transportation costs can be used to proxy for differences in net prices. In Russia, evergreens, such as fir, pine and spruce, are more valuable for the timber industry since Soviet-era wood processing equipment was designed for these species. To measure the percent of evergreen species we use Moderate Resolution Imaging Spectroradiometer imagery (MODIS). These data are from 2005 but are representative of the relative proportion of evergreen to deciduous trees across the study area. The average district in the study area has about 47 percent evergreen forest.

Accessibility to timber stands depends on biophysical conditions, such as slope and elevation, as well as the amount of infrastructure, such as roads. Slope is measured using NOAA's Global Land One-km Base Elevation Project and the average district in this study has a slope of less than one degree. Only slope is used in equations presented in this paper because of high correlation between slope and elevation in the study area. Road density gauges both accessibility of timber

[7] Data on regional-level stumpage prices were obtained for 1994-2002. Moscow sets the minimum stumpage price and regions then adjust this price; the final reservation price, however, is set for a timber auction based on quality of timber stock and transportation costs. We explored the relationship between regional stumpage prices (absolute and change over time) and logging and found the expected negative correlation between prices and timber harvested. In regression analysis, however, regional stumpage prices were negative but not statistically significant. Since we control for quality of timber and transportation costs at the district level we do not include regional stumpage prices in results presented in this paper.

stands and transportation costs. Road density is measured as the length of roads in a district; road data were generated from topographic maps of Russia produced around the collapse of the Soviet Union.

We also measure the distance from the center of a district to either Moscow city or St. Petersburg, depending on which city is closest, to control for transportation costs. The average distance is 528 km. While road density and distance to urban centers can be highly correlated in small study areas, we do not find this to be the case for this study.

Data on growing stock, *X*, in Russia are fraught with measurement errors (Kinnunen et al. 2007). Therefore, we use total forest area in a district as a proxy measure for growing stock. Data on total forest area come from the 2000-2005 remote sensing assessment by Potapov et al. (2011). These data provide an estimate of the total area of forest in 2000 and we approximate the area of forest in 1990 by adding the area of forest change from 1990-2000 to the 2000 measure of forest cover. The average area of forest cover is 1,895 km^2.

The time dummy, *T*, takes a value of "1" for 2000-2005 and a value of "0" otherwise. This variable controls for spatially invariant but time-varying factors such as global timber prices and Russia's export tariffs. Since most timber was exported (Carlsson and Olsson 1998), the time dummy, in combination with measures of type of timber, accessibility of timber stands, and transportation costs, should capture the variation in net timber prices across the study area.

Factors other than governance could affect the discount rate on timber harvesting. In particular, economic growth affects the opportunity costs of harvesting timber.[8] Since economic

[8] Lending, or interest, rates would also affect the timber industry's discount rate. Data on regional lending rates were not found; however, starting in 1998, regional data on the number of credit branches is available. In general, credit was a constraint to privatization in Russia, and did not become widely available until the late 1990s (Berkowitz and DeJong 2008). We tested the correlation between average number of credit branches for 1998-2000 and 2000-2005 with timber harvesting, but found no effect. We do not include number of credit branches as a covariate in this analysis.

growth could be correlated with governance controlling for this variable avoids omitted variables bias. Economic growth is measured at the regional level as the percent change in per capita gross domestic product (GDP). Data come from the national statistical database, Rosstat; however, no data exist before 1995 on GDP. Therefore, we take the change between 1995-2000 and 2000-2005 as our measure of economic growth; average economic growth for these two, five-year time periods is 21 percent.

Estimation Strategy

A reduced-form empirical model is used to estimate timber supply, with Equation 2 serving to motivate the choice of variables. In order to control for time-invariant regional differences, we estimate the model using fixed effects at the regional level. Regional fixed effects account for differences such as: historical legacies that affect present-day governance; climate and soil conditions that affect timber growth rates; the number of wood processing facilities since they remain largely unchanged in Russia since 1991 (Carlsson and Olsson 1997; Kortelainen and Kotilainen 2003); and other time-invariant differences. The reduced-form fixed-effects model can be written as:

$$Y_{ijt} = \alpha + \tau\theta_{jt} + \gamma P_{ijt} + \beta X_{ijt} + \kappa R_{jt} + \omega T_t + \mu_j + \varepsilon_{ijt}, \quad (4)$$

where Y_{ijt} is the amount of forest disturbance in district, *i*, nested in region, *j*, in time *t*; α is the regression constant; θ_{jt} is governance; P_{ijt} is the matrix of covariates measuring net prices; X_{ijt} is the vector of covariates measuring timber stock; R_{jt} is economic growth; T_t is the time dummy variable; μ_j are time-invariant regional fixed effects; ε_{ijt} is residual error; and the parameters to be estimated are τ, γ, β, κ, and ω. Note that this specification uses temporal and spatial variation to identify the impact of governance on logging.

Given the skewed distribution of forest disturbance we log-transform Y_{ijt} and covariates in P_{ijt} and X_{ijt}. Ferreira and Vincent (2010) test several functional forms for governance in their cross-country analysis and find a non-monotonic relationship. Similarly, we include quadratic and log-transformations of the governance measure in Equation 3, showing results for the log-transformed version when the turning point of the quadratic specification falls outside the range of the data. We test a quadratic specification for economic growth, R_{jt}, but the turning point is not within the range of the data; since this covariate can be negative it is not log-transformed.

Regional fixed effects, μ_j, are used because our variable of interest, θ_{jt}, is measured at the regional level. The inclusion of regional fixed effects controls for all time-invariant omitted variables specific to regions which could otherwise bias our estimates of governance. The within estimator is more conducive to causal analysis than the random effects model; choice of the within estimator is supported by the Hausman test for fixed effects found in Schaffer and Stillman (2010).

Cluster-robust standard errors, clustering at the regional level, are included to control for correlation in the residual error, ε_{ijt}. Cluster-robust standard errors allow spatial correlation across units: in our case, correlation across districts within the same region. Cluster-robust standard errors also control for most functional forms of serial correlation and heteroscedasticity in panel data (Cameron and Trivedi 2005).

In Equation 4 we check whether slopes are the same across the two time periods by interacting each covariate with the time dummy, T_t, and testing whether the estimated parameters are statistically the same. We present the first set of results without time interactions, with time interactions for slopes that are statistically different across time, and with time interactions for all covariates. Subsequent results only report time interactions for slopes that are statistically different across time.

Results

Econometric Output

The univariate relationship between governance and logging is shown in Figure 7. The graph suggests a quadratic relationship between these two variables. When we estimate Equation 4 we find a statistically significant and non-monotonic effect of governance on logging (Table 5).[9] Results are presented with no time interactions (Model A), with time interactions for all variables (Model C), and with time interactions for road density and distance to markets (Model B), since only these variables have statistically different coefficients across the two time periods. Only Model B is presented for other regressions in this paper. Panel A shows the non-monotonic effect of governance on logging and Panel B shows the marginal effect of governance on logging at the mean value of governance. Economic growth has a positive effect on logging and is statistically significant in Model B. All other covariates are statistically significant and, in general, follow neoclassical theory of timber supply (for a discussion of the effect of these parameters on logging see: Wendland et al., *submitted*). The overall explanatory power of this model is quite high, with a R^2 around 0.7. As comparison, we report results using a log-transformed value for governance and the different time interactions in Appendix I. These results also confirm a statistically significant relationship between governance and logging.

To interpret the magnitude of the effect of governance relative to other covariates we present the marginal effect on logging for a one-standard deviation change in the independent variables using Model B (Table 6). Governance has an impact similar in magnitude to biophysical

[9] We also tested three additional sample sizes. First, we omitted Moscow region. Potapov et al. (2011) find that forest disturbances not attributable to commercial logging (e.g., wildfires, wind damage, pests and disease) are a small proportion of forest loss in Russia, but that around Moscow city, there were substantial changes due to urbanization. Second, we omit the six regions that had no data on forest disturbances in 1990-2000. Third, we dropped the two regions that were outliers in Figure 6. Results were robust to all sample sizes and can be obtained by request from the authors.

variables like percent evergreen species, and a larger impact than several other covariates, including economic growth, slope and road density. The amount of forest cover in a district has the largest marginal impact on timber harvesting for a one-standard deviation change.

The turning point for governance in Model B is 3.5: regions scoring below this turning point would experience an increase in logging for a marginal increase in governance and regions scoring above 3.5 would experience a decrease. Figure 8.a. plots the marginal effect across the full range of governance values, illustrating the non-monotonic effect of governance on logging. The marginal effect of governance on logging is only statistically significant at the 95 percent confidence level for values below the turning point of 3.5. Thus, a marginal increase in governance at low levels of governance has a statistically significant and positive effect on logging rates, but a marginal increase in governance at high levels of governance has no statistical effect at the 95 percent confidence level.

Robustness Checks

While the estimate for our main variable of interest, θ_{jt}, is robust to correlation between regional governance and time-invariant regional unobservables, simultaneity bias between R_{jt} and Y_{ijt} could affect coefficient estimates.[10] To test the robustness of the main results we provide two checks.[11] First, we exclude regions that have more than 15, 10, and five percent of regional GDP from forestry activities and re-estimate Equation 4. In the full sample, the average percent of regional GDP from forestry activities – which includes timber, wood working, and pulp and paper mills – is about eight percent, with a maximum value of 56 percent. Without these additional regions

[10] Previous studies on governance and natural resource extraction use lagged measures of output per worker (Bohn and Deacon 2000) and value added per agricultural worker (Ferreira and Vincent 2010) to control for the opportunity costs of timber harvesting. However, even lagged values can introduce simultaneity bias if the process is dynamic.

[11] We performed a Durbin-Wu-Hausman test of endogeneity on economic growth following Davidson and MacKinnon (1993) and could not reject the null hypothesis that the model was unbiased (p-value of 0.6). However, the test of endogeneity is only consistent if the instruments for economic growth are exogenous, which we cannot prove. Therefore, we also provide results from instrumental regression analysis.

the average percent of regional GDP from forestry becomes five, four, and two percent for the respective samples.

The effect of governance on logging when regions with greater than 15 (Sample 1), 10 (Sample 2) and five (Sample 3) percent of GDP from forestry activities are excluded are similar to those from the full sample (Table 7). In Samples 1 and 2 the marginal effect of governance at the mean value is statistically similar to the results from the full sample (i.e., Table 5, Model B). The turning point for these samples is higher, at about four on the governance scale. In Sample 3, the turning point for governance is no longer within the range of values, so the log-transformed value of governance is presented. The size and significance on this log-transformed value is similar to results found using the full sample and the log-transformation of governance (i.e., Appendix I, Model B). When we plot the marginal effect of governance on logging from Table 7, Sample 1 we find a similar non-monotonic effect as in the full sample, but with larger standard errors (Figure 8.b.). Dropping regions reduces the sample size and therefore variation in the governance measure, making it harder to precisely estimate the effect of governance on logging. The effect of economic growth on logging is not statistically significant in these reduced samples, but the size of the coefficient is similar to the full sample. The signs and significance of most other covariates remain unchanged, and the overall model fit remains high with a R^2 around 0.6.

The second robustness check is to instrument for economic growth. Since economic growth is time-varying, the main challenge is finding a plausible instrument. Climate and geography are common instruments used in the literature for economic growth; unfortunately, the dependent variable in this analysis is strongly correlated with such factors. We identify two possible instruments for economic growth in Russia: change in output per worker and change in percent expenditures on alcohol. Output per worker measures industrial activity within a region and so excludes direct earnings from timber harvesting; however, it could still capture revenue from wood working and pulp and paper mills. Increasing alcohol consumption, and its related effects on health and mortality, is strongly associated with the rapid social and economic transition that occurred in Post-Soviet Russia (Bloom and Canning 2000), and is unlikely to directly affect timber harvesting. We use a measure of the percent change in expenditures on alcohol since data on actual consumption are not available. Summary statistics and correlation coefficients between these instruments and economic growth are in Appendix II. Both variables come from Russia's national statistical database, Rosstat. Output per worker is strongly positively correlated with economic growth in both time periods and the percent change in alcohol expenditures is strongly correlated in 1990-2000 and weakly correlated in 2000-2005.

Results using instrumental variables for economic growth are consistent with the original results (Table 8). We present results using output per worker as the only instrument and jointly with alcohol expenditures. Cluster-robust standard errors are used. We also restrict the sample to exclude regions with more than 15, 10, and five percent of GDP from forestry activities. When the sample is restricted (i.e., Samples 1-3) the size of the governance coefficient decreases and the standard errors increase, but the marginal effect at the mean value remains statistically significant and of similar magnitude. In Sample 3, governance again exhibits a monotonic relationship with logging and so the log-transformation is used. Economic growth is weakly significant in most specifications and the size of the coefficient is statistically similar to when economic growth is not instrumented. The estimated parameters for all other covariates are similar to the results presented in Table 5.

In Panel D, the statistical tests provide confidence in our choice of instruments. Underidentification tests whether the excluded instruments are correlated with economic growth. Both specifications and all sample sizes reject the null hypothesis of underidentification at the 95 percent level or higher. Weak identification tests whether the excluded instruments are only weakly correlated with economic growth. With cluster-robust standard errors, the Kleibergen-Paap Wald F-statistic is presented but critical values are not available. Baum et al. (2007) suggest that the critical values from the Stock and Yogo (2005) test that assumes i.i.d. standard errors can be used with caution, or that the general "rule of thumb" that the F-statistic should be at least 10, can be used. F-statistics are all larger than 10 in Panel D and using the Stock and Yogo (2005) critical values (not presented) the null hypothesis of weak identification is rejected. Finally, the null hypothesis that instruments are uncorrelated with the error term can be tested when more than one instrument is excluded. This overidentification test is presented for the second specification, and fails to reject the null hypothesis that these instruments are uncorrelated with the error term in our model.

The marginal effect of governance on logging using parameters from Table 8 (Figures 8.c. and 8.d.) shows a similar pattern as found when we do not instrument for economic growth (i.e., Figures 8.a. and 8.b.). In both the full sample and when regions with greater than 15 percent of GDP from forestry are excluded, governance has a non-monotonic effect on logging. This effect is statistically significant at the 95 percent level for values below the turning point, but is not statistically significant at higher values of governance. Similar to the result in 4.b, we find that as the sample size is reduced, the confidence interval increases around the estimated coefficients.

Falsification Test

As a final check on the main results we randomly assign governance measures within the range of the data, i.e., 1.5 to 4.5, to regions. We do this five times and re-estimate the parameters in Equation 4. An insignificant effect on these "false" governance scores helps eliminate concern of spurious correlation between our main variable of interest and logging. Summary statistics for randomly generated governance measures are presented in Appendix III. Overall, the average value on these randomly generated governance measures is slightly less than the average value found in Table 3. Regression results using these generated values of governance are presented in Table 9. We do not find a statistically significant relationship between governance and logging in the falsification tests, providing additional support that our results in Tables 5, 7, and 8 are not spurious.

Extensions

Unbundling Governance

In Tables 5-9, governance measures both political institutions and state capacity and effectiveness. To tease out whether certain aspects of governance are more important than others, we re-estimate Equation 4 using average values of governance indicators specific to the two categories (Table 4). Political institutions refers to who has power and how they got it; in this analysis, it refers to participation of civil society in governance, free and fair election of leaders, political stability, and competition in elections. Political institutions would affect logging independent of other indicators of governance if the type of political leader (e.g., more autocratic versus democratic), or public participation in governance, influenced firm decisions. State capacity and effectiveness refers to the ability of the state to coherently and efficiently implement policies and control corruption; in this analysis, it refers to presence of an independent media, transparent government, balance of powers and judicial independence, and strength of district governments. State capacity and effectiveness would affect logging independent of other indicators if it affected the prevalence of bribes (e.g., through an independent media or government transparency) or the ability of the government to uphold property rights (e.g., through an independent judiciary or strong local governments). Summary statistics for the two components of governance are similar to the full governance measure with average values around three and a range of 1.5 to 4.5.

In Figure 9 we plot the relationship between political institutions and area harvested and state capacity and area harvested. The shape of the two graphs varies slightly: political institutions have a quadratic relationship with area harvested, whereas state capacity and effectiveness has a linear relationship with logging. Similar relationships are found when we include the two governance components in Equation 4 as separate covariates; therefore we specify political institutions as a quadratic variable and state capacity as a log-transformed variable. We find a statistically significant and positive effect of state capacity and effectiveness on logging (Table 10). This effect is similar in magnitude to the full log-transformed governance measure in Appendix I, Model B. The effect of political institutions is weaker. The marginal effect is significant at the 90 percent level, but only at the tail ends of the distribution.

Lease Contracts

We use regional data on area of timberland leased and number of lease contracts to further explore the relationship between governance and property rights. These data come from the Federal Agency of Forestry in Russia; the first leases were in 1994. Figure 8.A. shows the percent of total forest area in a region that is leased across the full range of governance values. While there is high variance at the upper range of governance values, the overall pattern suggests a positive relationship between better governance and percent of forest land leased. Figure 8.B. shows the relationship between total number of lease contracts and governance. Again, the relationship suggests that regions with better governance have more lease contracts, all else being equal. Graphs between political institutions and leases and state capacity and leases showed similar patterns, and are not presented here.

Conclusion

This paper contributes to a growing body of literature on the political economy of natural resource extraction (Bohn and Deacon 2000; Ferreira and Vincent 2010). Our results are similar to those in the cross-country analysis by Ferreira and Vincent (2010), and suggest a relationship between governance and logging that differs from the relationship between governance and deforestation. This has important environmental implications, since policy prescriptions focus on improving governance in order to reduce deforestation and illegal logging (Barbier et al. 2005; Bulte et al. 2007; Burgess et al. 2011). Our results, however, suggest that improving governance can also encourage more capital-intensive resource use, such as commercial logging, in areas where governance currently constrains large-scale extraction of resources.

While the direction of impact is clear, what is less definitive in our analysis than in the cross-country analysis by Ferreira and Vincent (2010), is whether the relationship between governance and logging is strictly non-monotonic, or in some cases, monotonic. This relationship might depend, in part, on current forest stock and harvesting rates. Russia has vast timber resources, and in some regions, timber harvesting was reduced to 30 percent of Soviet-era quantities (Carlsson et al. 2000), and national forest output was at about 23 percent of annual allowable cut in 2003 (Torniainen et al. 2006). Thus, the opportunity to increase timber harvesting exists in Russia, but whether harvesting is sustainable is debatable given poor forest management records and a depletion of older, and more valuable, timber stock (Shvidenko and Nilsson 1996; Mayer et al. 2005). Our results, similar to previous research, does not provide information about the long-term economic or ecological impacts of increased harvest rates that might come with better governance in Russia.

The within-country and remote sensing data used in this analysis minimizes potential omitted variables and measurement bias, and is a contribution to the literature. Using the within-country data we find that the relationship between governance and logging not only holds across countries but also within the same country. This is an important finding given the emphasis on decentralization by policymakers for economic growth and natural resource management (Colfer and Capistrano 2005; Bartley et al. 2008). Post-Soviet Russia consists of several heterogeneous regions; similar variations in governance are found across many other countries and at the community level. When governance is decentralized it is likely that the implementation and enforcement of policies will vary, and therefore land use patterns will differ. Using the remote sensing data we are able to capture both legal and illegal logging activity. Illegal logging takes many forms in Russia, including harvesting outside of established areas, harvesting in excess of timber licenses, and cutting protected species. While we cannot determine the relative proportion of legal versus illegal logging across our study area, we do find that at the district level, total amount of logging is higher in areas with better governance.

Additionally, this paper provides insight on the mechanisms through which governance affects timber harvesting in Russia. Timber firms rely on state employees for access to and enforcement of forest property rights in Russia. By separating governance into political institutions and state capacity and effectiveness we find that the latter has a much stronger impact on logging decisions. State capacity and effectiveness captures the ability of a region to coherently and efficiently implement policies and control corruption, which would affect the ability of firms to negotiate fair timber contracts and enforcement of contracts. These results, combined with information on the relationship between governance and leases in Russia, suggest that access to property was an impediment to timber firms. This is consistent with qualitative reports on the high fees and bribes faced by private timber firms in Post-Soviet Russia (Eikeland et al. 2004; Torniainen et al. 2006).

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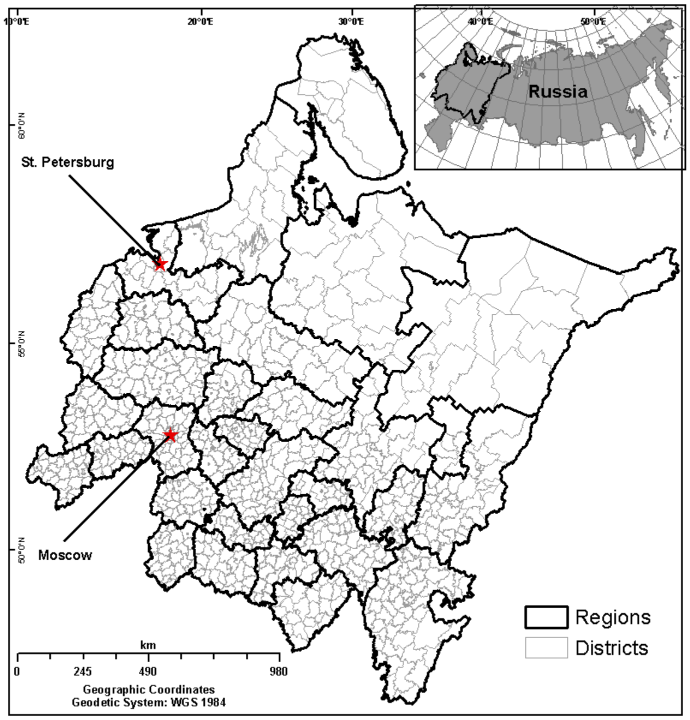


Figure 5. Map of study area

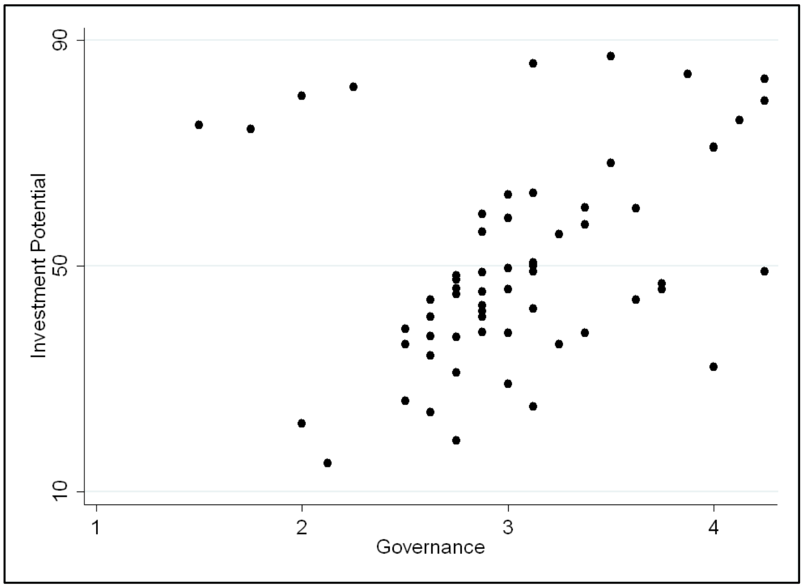


Figure 6. Governance versus ranking of investment potential by region

Note: Governance is the average value of indicators measuring political institutions and state capacity and effectiveness; indicators come from the Carnegie Center Moscow. Scores range from 1.5 to 4.3 with higher representing better governance. Investment potential is the average annual ranking given by Expert RA Ranking Agency to a region and is based on the composite investment potential of economic, political, social, and biophysical factors. Regions are ranked from 1 to 89; in this graph 89 indicates the highest investment potential. There are 62 observations: 31 regions with values for two time periods.

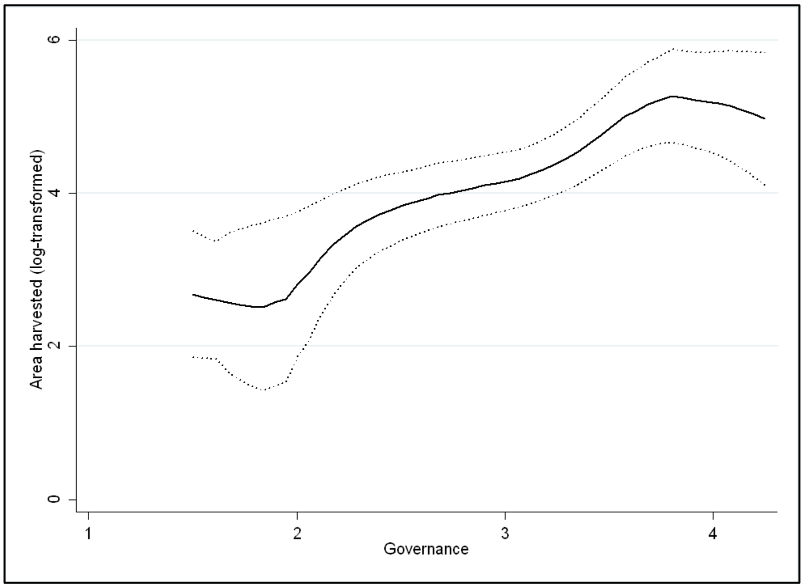
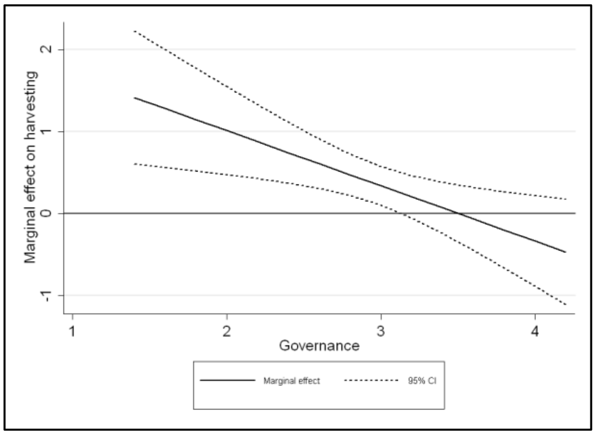
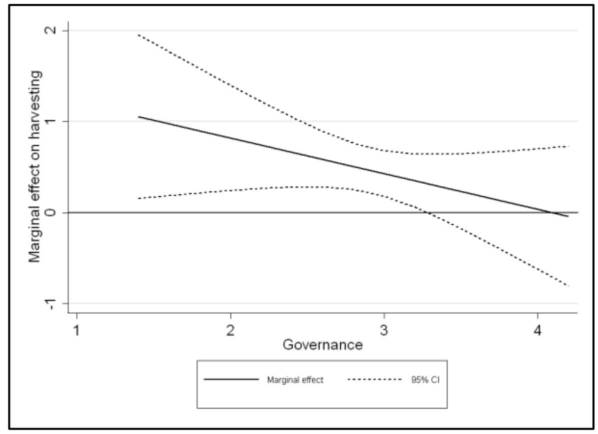


Figure 7. Area harvested by governance

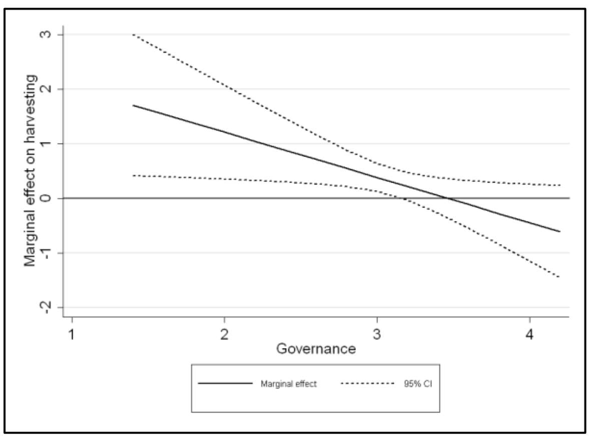
Note: Results from polynomial regression (bandwidth = 0.3) of governance on the log-transformed value of area harvested. Dotted line is the 95% confidence interval. Regional data are used (N=62).



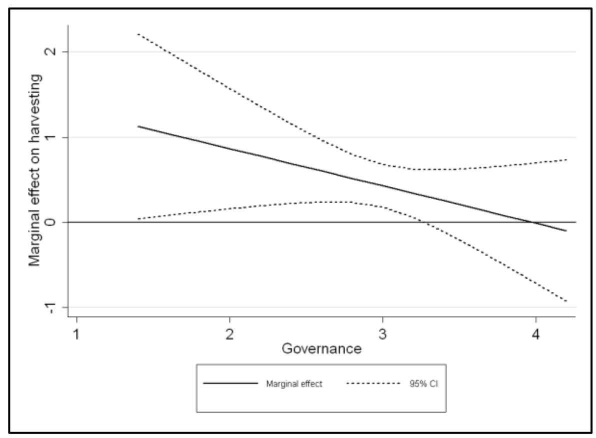
A



B



C



D

Figure 8. Marginal effect of governance on harvesting: A) Table 5, Model B; B) Table 7, Sample 1; C) Table 8, Output and Alcohol, Full Sample; D) Table 8, Output and Alcohol, Sample 1

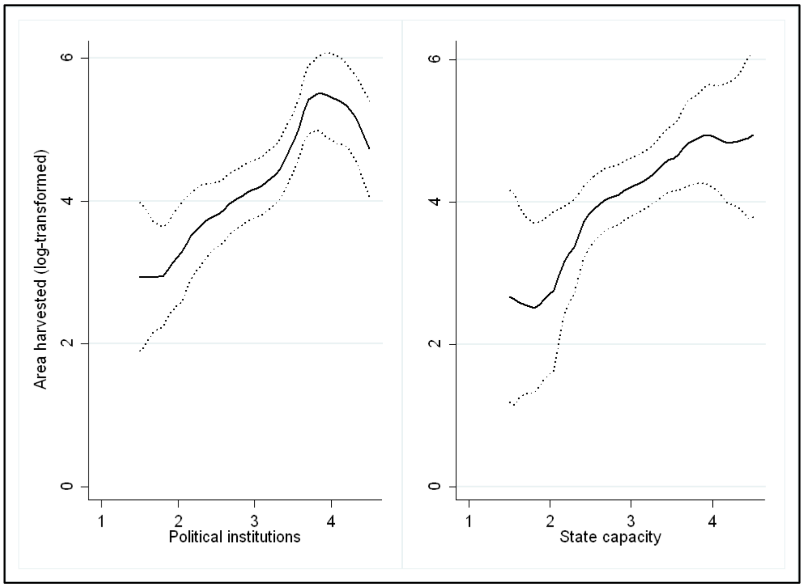
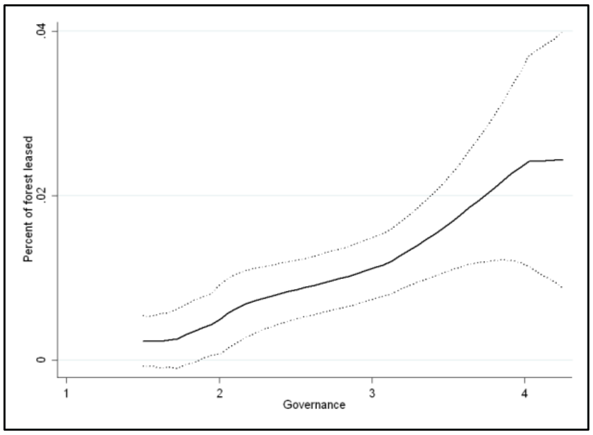
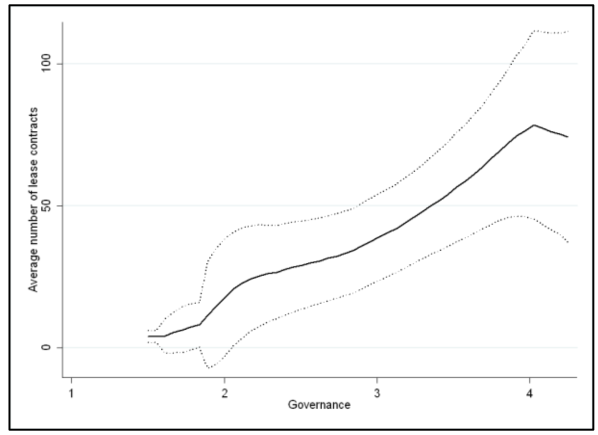


Figure 9. Area harvested by political institutions and state capacity and effectiveness

Note: Results from polynomial regression (bandwidth = 0.3) of political institutions and state capacity and effectiveness on the log-transformed value of area harvested. Dotted line is the 95% confidence interval. Regional data are used (N=62).





A **B**

Figure 10. A) Relationship between governance and percent of total forest land leased to private firms; B) Relationship between governance and number of timber contracts

Note: Results from polynomial regression (bandwidth = 0.4). Dotted line is the 95% confidence interval. Regional data are used (N=62). Percent of total forest land leased calculated as average area leased during time period (e.g., 1990-2000 or 2000-2005) divided by total forest area. Number of timber contracts calculated as average number of contracts during time period.

Table 3. Description, data source and summary statistics for data

Panel A: Description and data source

Variable	Description	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[a] (described in: Potapov et al., 2011)
Governance	Average measure of 8 indicators (see Table 4); possible range of 1 to 5, with 5 high	Carnegie Center Moscow (Petrov 2005) and online[b]
Evergreen	Percent of evergreen forest in 2005; time-invariant	Moderate Resolution Imaging Spectroradiometer imagery
Slope	Average variation in slope (degrees); time-invariant	NOAA's Global Land 1-km Base Elevation Project
Road density	Total length of roads (meters) in a district divided by area of that district (m^2); time-invariant	1:500,000 topographic maps published around 1990
Distance	Distance (km) from centroid of a district to closest market, defined as either Moscow city or St. Petersburg; time-invariant	Calculated by authors
Forest area	Total forest area (km^2)	2000 measure from Boreal Forest Monitoring Project and 1990 measure recreated by authors (see text)
Economic growth	Percent change in per capita gross regional product	National statistical database, Rosstat
Time dummy	Value of "0" for 1990-2000 and "1" for 2000-2005	Authors' creation

Panel B: Summary statistics

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Forest disturbance (km2)	1,476	6	15	0	215
Governance (1-5)	62	3.1	0.6	1.5	4.3

Evergreen (%)	1,476	47	36	0	100
Slope (degrees)	1,476	0.74	0.57	0	5.78
Road density (m/ m2)	1,476	0.01	0.03	0	0.40
Distance (km)	1,476	528	327	0	1,837
Forest area (km2)	1,476	1,895	3,706	0.06	33,957
Economic growth	62	21	26	-33	69

[a]http://kea.sdstate.edu/projects/boreal/
[b]http://www.socpol.ru/atlas/indexes/index_democr.shtml

Table 4. Definitions of indicators used in governance measure

Indicator	Category	Description
Civil society	Political institution	NGOs, referenda, freedom of public political activity such as rallies and demonstrations
Free and fair elections	Political institution	Free and fair elections at national, regional and local levels
Political stability	Political institution	Existence of stable political parties; representation of parties in regional legislatures
Competition in elections	Political institution	Existence of multiple political parties; effectiveness of leadership changes through elections
Independence of media	State capacity and effectiveness	Independence of the media from authorities
Government transparency	State capacity and effectiveness	Transparency of regional political life
Balance of powers	State capacity and effectiveness	Real balance of power between the executive and the legislative branches, independence of judiciary and law enforcement
District government	State capacity and effectiveness	Quality of district governments

Note: Indicator names and descriptions are based on http://www.socpol.ru/atlas/indexes/index_democr.shtml and Libman (2010); however, some names have been changed to more fully represent their definitions. The authors' created "category" based on the definition of governance in Baland et al. (2010).

Table 5. Panel data results

Variable	Model A	Model B	Model C
Panel A: Regression output			
Governance	1.695 (1.630)	2.355*** (0.726)	2.333** (1.030)
Governance squared	-0.198 (0.273)	-0.336*** (0.120)	-0.324* (0.163)
Governance*time dummy			0.711 (0.493)
Governance squared*time dummy			-0.115 (0.073)
Economic growth	0.006*** (0.002)	0.003** (0.001)	0.002 (0.002)
Economic growth*time dummy			-0.000 (0.003)
Ln(Forest area)	0.345*** (0.034)	0.344*** (0.034)	0.374*** (0.045)
Ln(Forest area)*time dummy			-0.047 (0.031)
Ln(Evergreen)	0.928*** (0.144)	0.928*** (0.144)	0.968*** (0.206)
Ln(Evergreen)*time dummy			-0.069 (0.148)
Ln(Slope)	-0.510*** (0.156)	-0.490*** (0.152)	-0.368** (0.170)
Ln(Slope)*time dummy			-0.176 (0.171)
Ln(Road density)	4.721*** (1.164)	5.558*** (1.157)	6.789*** (1.611)

Ln(Road density)*time dummy		-1.634***	-3.585***
		(0.372)	(1.079)
Ln(Distance)	0.248***	0.401***	0.367***
	(0.073)	(0.076)	(0.079)
Ln(Distance)*time dummy		-0.302***	-0.252***
		(0.049)	(0.068)
Time dummy	-0.190*	1.785***	0.908
	(0.099)	(0.318)	(0.973)
Constant	-5.884**	-7.497***	-7.647***
	(2.366)	(1.152)	(1.605)
Panel B: Marginal effect of governance at mean value			
Governance + Governance squared	0.505***	0.337***	0.391***
	(0.169)	(0.115)	(0.125)
Governance + Governance squared + Governance*time dummy + Governance squared*time dummy			0.410**
			(0.174)
Panel C: Additional information			
Observations	1,476	1,476	1,476
Number of regions	31	31	31
R^2 (overall)	0.71	0.74	0.73

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the log-transformed value of area of timber harvested. Model A has no time interactions; Model B has time interactions for road density and distance; Model C has time interactions for all variables. Standard errors are clustered at the regional level. The unit of observation is districts.

Table 6. Marginal effect on harvesting for one standard deviation change in independent variable

Variable	Model B
Governance	0.202*** (0.069)
Economic growth	0.071** (0.030)
Ln(Forest area)	0.653*** (0.065)
Ln(Evergreen)	0.232*** (0.036)
Ln(Slope)	-0.118*** (0.036)
Ln(Road density)	0.167*** (0.034)
Ln(Road density)*time dummy	0.118*** (0.036)
Ln(Distance)	0.321*** (0.061)
Ln(Distance)*time dummy	0.080 (0.062)

*** p<0.01, ** p<0.05, * p<0.1

Note: Table shows the marginal effect for a one standard deviation change in the independent variable on the log-transformed value of area harvested based on regression output from Table 5, Model B.

Table 7. Panel data results dropping regions with high percent growth from forestry

Variable	**Model B**		
	Sample 1	**Sample 2**	**Sample 3**
Panel A: Regression output			
Governance	1.591*	1.765*	
	(0.930)	(1.017)	
Governance squared	-0.196	-0.219	
	(0.156)	(0.168)	
Ln(Governance)			1.620***
			(0.512)
Economic growth	0.002	0.002	0.002
	(0.001)	(0.002)	(0.002)
Ln(Forest area)	0.305***	0.309***	0.255***
	(0.027)	(0.031)	(0.026)
Ln(Evergreen)	0.838***	0.769***	0.553***
	(0.110)	(0.118)	(0.142)
Ln(Slope)	-0.378**	-0.411**	-0.499***
	(0.172)	(0.186)	(0.135)
Ln(Road density)	4.404***	4.347***	4.161***
	(0.902)	(0.889)	(1.071)
Ln(Road density)*time dummy	-1.789***	-1.627***	-2.371***
	(0.373)	(0.425)	(0.647)
Ln(Distance)	0.304***	0.274***	0.097
	(0.061)	(0.062)	(0.074)
Ln(Distance)*time dummy	-0.263***	-0.264***	-0.313**
	(0.066)	(0.078)	(0.123)
Time dummy	1.596***	1.600***	2.015**
	(0.416)	(0.511)	(0.828)

Constant	-5.830***	-5.958***	-3.480***
	(1.499)	(1.641)	(0.691)
Panel B: Marginal effect of governance at mean value			
Governance + Governance squared	0.415***	0.448***	
	(0.124)	(0.133)	
Panel C: Additional information			
Observations	1,243	1,089	669
Number of regions	26	22	16
R^2 (overall)	0.66	0.64	0.56

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the log-transformed value of area of timber harvested. Model B has time interactions for road density and distance. Standard errors are clustered at the regional level. The unit of observation is districts. Sample 1 includes regions with less than 15 percent of gross regional product from forestry; Sample 2 includes regions with less than 10 percent of gross regional product from forestry; Sample 3 includes regions with less than 5 percent of gross regional product from forestry.

Table 8. Panel data results using instrumental variables for economic growth

Variable	Model B							
	Instruments							
	Output	Output	Output	Output	Output and Alcohol	Output and Alcohol	Output and Alcohol	Output and Alcohol
	Full sample	Sample 1	Sample 2	Sample 3	Full sample	Sample 1	Sample 2	Sample 3
Panel A: Regression output								
Governance	2.870**	1.719*	1.937*		2.924**	1.741*	1.914*	
	(1.138)	(0.971)	(1.118)		(1.154)	(0.978)	(1.107)	
Governance squared	-0.414**	-0.215	-0.246		-0.422**	-0.219	-0.242	
	(0.182)	(0.161)	(0.182)		(0.184)	(0.162)	(0.180)	
Ln(Governance)				1.734***				1.736***
				(0.431)				(0.432)
Economic growth	0.005*	0.003*	0.003*	0.004	0.005*	0.003*	0.003	0.004
	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)
Ln(Forest area)	0.344***	0.305***	0.309***	0.256***	0.344***	0.305***	0.309***	0.256***
	(0.033)	(0.027)	(0.030)	(0.025)	(0.033)	(0.027)	(0.030)	(0.025)
Ln(Evergreen)	0.929***	0.838***	0.770***	0.554***	0.930***	0.838***	0.770***	0.554***
	(0.142)	(0.108)	(0.116)	(0.138)	(0.142)	(0.108)	(0.115)	(0.138)
Ln(Slope)	-0.494***	-0.379**	-0.413**	-0.507***	-0.494***	-0.379**	-0.413**	-0.508***
	(0.150)	(0.169)	(0.181)	(0.132)	(0.150)	(0.169)	(0.181)	(0.132)
Ln(Road density)	5.652***	4.420***	4.378***	4.195***	5.662***	4.423***	4.374***	4.196***
	(1.167)	(0.887)	(0.871)	(1.034)	(1.171)	(0.888)	(0.869)	(1.034)
Ln(Road density)*time dummy	-1.803***	-1.816***	-1.679***	-2.391***	-1.820***	-1.821***	-1.672***	-2.392***
	(0.426)	(0.384)	(0.433)	(0.622)	(0.431)	(0.384)	(0.433)	(0.622)
Ln(Distance)	0.391***	0.302***	0.268***	0.088	0.390***	-1.821***	-1.672***	-2.392***
	(0.078)	(0.062)	(0.064)	(0.077)	(0.079)	(0.384)	(0.433)	(0.622)
Ln(Distance)*time dummy	-0.282***	0.302***	0.268***	0.088	-0.280***	-0.258***	-0.254***	-0.277**
	(0.048)	(0.062)	(0.064)	(0.077)	(0.048)	(0.062)	(0.073)	(0.121)

Time dummy	1.573***	1.545***	1.485***	1.737**	1.551***	1.536***	1.500***	1.732**
	(0.346)	(0.393)	(0.471)	(0.828)	(0.343)	(0.391)	(0.474)	(0.825)
Panel B: Marginal effect of governance at mean value								
Governance + Governance squared	0.387***	0.427***	0.463***		0.382***	0.427***	0.463***	
	(0.125)	(0.123)	(0.132)		(0.122)	(0.122)	(0.132)	
Panel C: Additional information								
Observations	1,476	1,243	1,089	669	1,476	1,243	1,089	669
Number of regions	31	26	22	16	31	26	22	16
R^2 (centered)	0.55	0.56	0.56	0.54	0.55	0.57	0.55	0.54
Panel D: Test of instruments								
Underidentification test, Chi-squared p-value	0.007***	0.012**	0.012**	0.011**	0.023**	0.037**	0.041**	0.032**
Weak identification test, Wald F-statistic	23.770	64.805	61.523	51.404	14.528	32.806	30.792	29.168
Overidentification test, Chi-squared p-value					0.424	0.725	0.758	0.616

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the log-transformed value of area of timber harvested. Model B has time interactions for road density and distance. Standard errors are clustered at the regional level. The unit of observation is districts. Sample 1 includes regions with less than 15 percent of gross regional product from forestry; Sample 2 includes regions with less than 10 percent of gross regional product from forestry; Sample 3 includes regions with less than 5 percent of gross regional product from forestry. In Panel D, test statistics were generated using Stata 11. The underidentification test is the Lagrange Multiplier test of whether the equation is identified; the null is that the equation is underidentified. The weak identification test is the cluster-robust Kleibergen-Paap Wald F-statistic; critical values are not reported for this test but a "rule of thumb" is that a F-statistic greater than 10 rejects the null hypothesis of weak identification (Baum et al. 2007). The overidentification test is Hansen's J Statistic and is only calculated when there is more than one excluded instrument; the joint null hypothesis is that the instruments are valid instruments.

Table 9. Panel data results from falsification test

Variable	Model B				
	Draw 1	**Draw 2**	**Draw 3**	**Draw 4**	**Draw 5**
Panel A: Regression output					
Governance	-0.157	0.042	0.054	0.277	
	(0.129)	(0.268)	(0.164)	(0.165)	
Governance squared	0.024	-0.007	-0.011	-0.050*	
	(0.020)	(0.044)	(0.026)	(0.028)	
Ln(Governance)					-0.054
					(0.093)
Economic growth	0.0001	0.0001	-0.0001	0.001	0.001
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Ln(Forest area)	0.344***	0.344***	0.344***	0.344***	0.344***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Ln(Evergreen)	0.921***	0.921***	0.921***	0.921***	0.920***
	(0.144)	(0.143)	(0.144)	(0.143)	(0.144)
Ln(Slope)	-0.474***	-0.473***	-0.472***	-0.469***	-0.471***
	(0.150)	(0.150)	(0.151)	(0.151)	(0.150)
Ln(Road density)	5.472***	5.409***	5.430***	5.458***	5.433***
	(1.155)	(1.155)	(1.154)	(1.154)	(1.137)
Ln(Road density)*time dummy	-1.446***	-1.335***	-1.382***	-1.435***	-1.371***
	(0.441)	(0.399)	(0.416)	(0.375)	(0.420)
Ln(Distance)	0.409***	0.412***	0.415***	0.410***	0.407***
	(0.075)	(0.075)	(0.075)	(0.072)	(0.078)
Ln(Distance)*time dummy	-0.317***	-0.321***	-0.325***	-0.319***	-0.312***
	(0.046)	(0.046)	(0.042)	(0.037)	(0.049)
Time dummy	2.023***	2.035***	2.079***	1.991***	1.977***
	(0.287)	(0.301)	(0.287)	(0.251)	(0.321)

Constant	-3.445***	-3.736***	-3.746***	-3.997***	-3.588***
	(0.559)	(0.543)	(0.553)	(0.551)	(0.557)
Panel B: Marginal effect of governance at mean value					
Governance + Governance squared	-0.013	0.002	-0.012	-0.023	
	(0.026)	(0.012)	(0.020)	(0.030)	
Panel C: Additional information					
Observations	1,476	1,476	1,476	1,476	1,476
Number of regions	31	31	31	31	31
R^2 (overall)	0.72	0.73	0.73	0.73	0.73

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the log-transformed value of area of timber harvested. Model B has time interactions for road density and distance. Standard errors are clustered at the regional level. The unit of observation is districts. In draw 5, the turning point for governance is not within the range of the data so a log-transformation is used.

Table 10. Panel data results using political institutions and state capacity and effectiveness

Variable	Model B
Panel A: Regression output	
Political institutions	0.700*
	(0.386)
Political institutions squared	-0.118*
	(0.059)
Ln(State capacity)	1.537***
	(0.502)
Economic growth	0.004**
	(0.002)
Ln(Forest area)	0.344***
	(0.034)
Ln(Evergreen)	0.924***
	(0.143)
Ln(Slope)	-0.488***
	(0.152)
Ln(Road density)	5.399***
	(1.124)
Ln(Road density)*time dummy	-1.295***
	(0.378)
Ln(Distance)	0.379***
	(0.078)
Ln(Distance)*time dummy	-0.264***
	(0.055)
Time dummy	1.544***
	(0.363)
Constant	-6.598***
	(0.746)

Panel B: Marginal effect of governance at mean value	
Political institutions + Political institutions squared	-0.010
	(0.085)
Panel C: Additional information	
Observations	1,476
Number of regions	31
R^2 (overall)	0.73

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the log-transformed value of area of timber harvested. Model B has time interactions for road density and distance. Standard errors are clustered at the regional level. The unit of observation is districts. We define state capacity and effectiveness as the average value of independence of the media, government transparency, political organization and local governance, and political institutions as the average value of the other four indicators in Table 4.

Appendix I. Panel data results using log-transformed value of governance

Variable	Model A	Model B	Model C
Panel A: Regression output			
Ln(Governance)	1.876** (0.753)	1.156** (0.531)	1.209** (0.460)
Ln(Governance)*time dummy			-0.252 (0.218)
Economic growth	0.006*** (0.002)	0.001 (0.001)	0.000 (0.001)
Economic growth*time dummy			0.002 (0.003)
Ln(Forest area)	0.345*** (0.034)	0.344*** (0.034)	0.373*** (0.045)
Ln(Forest area)*time dummy			-0.045 (0.030)
Ln(Evergreen)	0.927*** (0.144)	0.926*** (0.143)	0.969*** (0.209)
Ln(Evergreen)*time dummy			-0.070 (0.154)
Ln(Slope)	-0.506*** (0.154)	-0.482*** (0.149)	-0.360* (0.176)
Ln(Slope)*time dummy			-0.196 (0.176)
Ln(Road density)	4.726*** (1.167)	5.511*** (1.149)	6.629*** (1.573)
Ln(Road density)*time dummy		-1.519*** (0.415)	-3.293*** (1.005)
Ln(Distance)	0.248*** (0.073)	0.395*** (0.076)	0.369*** (0.079)

Ln(Distance)*time dummy		-0.290***	-0.255***
		(0.053)	(0.072)
Time dummy	-0.160*	1.771***	2.348***
	(0.079)	(0.350)	(0.597)
Constant	-5.247***	-5.161***	-5.377***
	(1.247)	(0.850)	(0.774)
Panel B: Marginal effect of governance at mean value			
Ln(Governance) + Ln(Governance)*time dummy			0.957*
			(0.537)
Panel C: Additional information			
Observations	1,476	1,476	1,476
Number of regions	31	31	31
R^2 (overall)	0.71	0.73	0.74

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the log-transformed value of area of timber harvested. Model A has no time interactions; Model B has time interactions for road density and distance; Model C has time interactions for all variables. Standard errors are clustered at the regional level. The unit of observation is districts.

Appendix II. Summary statistics and correlations for instrumental variables

Instrument	Mean	Standard deviation	Minimum	Maximum	Correlation with economic growth 1995-2000	Correlation with economic growth 2000-2005
Output per worker	13.73	25.52	-40.73	62.75	0.82	0.68
Percent of expenditures on alcohol	-13.18	26.81	-59.38	100	0.54	0.32

Note: Output per worker and percent of expenditures on alcohol are measured in percent change over 1995-2000 and 2000-2005. Economic growth is also measured as percent change over 1995-2000 and 2000-2005.

Appendix III. Summary statistics for randomly generated governance scores

Random draw	Mean	Standard deviation	Minimum	Maximum
1	2.78	1.16	1.5	4.5
2	2.89	1.08	1.5	4.5
3	2.84	1.06	1.5	4.5
4	2.95	1.05	1.5	4.5
5	2.86	1.01	1.5	4.5

Note: Random integers between 1.5 and 4.5 were assigned to regions using the random number generator in Stata 11.

CHAPTER 3: Biodiversity conservation during times of transition: the effectiveness of protected areas in European Russia between 1985 and 2010

Status: In preparation for *Conservation Biology*

Abstract

The number of protected areas in Russia increased rapidly right before and after the collapse of the Soviet Union. However, political and economic changes within the country meant that budgets for conservation plummeted, while illegal poaching and logging increased. In this paper, we used state-of-the-art impact evaluation methods to measure the effectiveness of protected areas in European Russia in preventing logging before, during and after the collapse of the Soviet Union. We found that strict protected areas ('zapovedniks') prevented logging after 1995, but were not effective between 1985 and 1995. Two other types of federally protected areas (national parks and 'zakazniks'), however, did not prevent logging compared to non-protected areas with similar characteristics. These findings suggest that non-violent periods of political and socioeconomic upheaval can undermine biodiversity protection. Additionally, our analysis shows the importance of controlling for selection and hidden bias when measuring conservation effectiveness.

Keywords: impact evaluation, logging, matching, protected areas, Russia

Introduction

Protected areas are a cornerstone for the conservation of biodiversity and ecosystem services (Pimm et al. 2001; Rodrigues et al. 2004; UNEP-WCMC 2008). Protected areas currently cover 13 percent of terrestrial land, with continuing efforts to increase this area in order to more fully conserve species diversity (Brooks et al. 2004; Balmford et al. 2005; Jenkins and Joppa 2009). Global climate policies may also target protected areas for their contributions to reducing carbon emissions through avoided deforestation (Scharlemann et al. 2010). Thus, the ability of protected areas to conserve biodiversity and ecosystem services within their boundaries is imperative to biodiversity and human well-being.

Protected areas face many threats in conserving biodiversity and provisioning ecosystem services. Protected areas are often inadequately funded and staffed (Bruner et al. 2001), and are increasingly called on to meet multiple social and ecological objectives (Dudley et al. 1999; Naughton-Treves et al. 2005; West et al. 2006). They also face many broader, and often unanticipated, challenges, including climate change, war, and large political and socioeconomic upheavals. While there is an increasing interest in how climate change will impact biodiversity conservation (Hannah 2008; Loarie et al. 2009), and there are several studies on the impacts of war on biodiversity conservation (Balmford et al. 2001; De Jong et al. 2007; Hanson et al. 2009), there is very little understanding on how protected areas fare during times of non-violent political and socioeconomic change.

The break-down of the Soviet Union was perhaps the largest non-violent political and socioeconomic change in recent history, leading to rapid and unprecedented land use changes such as agricultural abandonment and decreased commercial logging (Ioffe et al. 2004; Eikeland et al. 2004). The political and socioeconomic changes following the collapse of the Soviet Union had direct impacts on biological conservation. In some cases, wildlife populations increased due to expanding habitat (Baskin and Danell 2003; Stephens et al. 2006; Enserink and Vogel 2006; Alcantara 2010). However, illegal activities also increased, for example, poaching of saiga antelope (Milner-Gulland et al. 2001) and illegal logging (Kummerle et al. 2009) have both been documented. Despite an increasing number of protected areas in former Soviet countries right before and after the fall (Radeloff et al., *in preparation*), there has been no analysis of how effective protected areas were at conserving biodiversity during this transition period.

In this paper we measured the effectiveness of protected areas in European Russia at preventing logging between 1985 and 2010. Forest disturbance in Russia is primarily due to logging and can be observed with satellite imagery (Potapov et al. 2011; Baumann et al., *in preparation*). Measuring forest disturbance as an indicator of protected area effectiveness is useful because forest cover is correlated with species habitat and carbon storage (Joppa and Pfaff 2011). Measuring the impact of Russia's protected areas is important locally given calls to increase the protected area network (Krever et al. 2009), and globally, in order to understand the impact that periods of non-violent political and socioeconomic change can have on biodiversity conservation.

Russia underwent several political and socioeconomic changes after the collapse of the Soviet Union, including government decentralization and shifting to a market-based economy. One of the most significant changes for conservation was decreased federal financing for conservation areas; one estimate puts post-transition budgets as low as 90 percent of their 1989 levels (Wells and Williams 1998). Additionally, legislation and governance of conservation areas changed several times in Russia after 1991, leading to ministerial confusion over management responsibilities (Sobolev et al. 1995; Colwell et al. 1997; Pryde 1997). These conditions created opportunities for illegal exploitation of timber and other resources within conservation areas; these threats are considered higher in the European part of Russia because of its proximity to human settlement (Sobolev et al.

1995).

A major complication of measuring the effectiveness of protected areas is that where they are placed on the landscape is non-random (Mas 2005; Andam et al. 2008; Joppa and Pfaff 2009; Joppa and Pfaff 2010). A global study finds that most protected areas are located in places unsuitable for other economic activities (Joppa and Pfaff 2009). Previous studies of protected area effectiveness that fail to account for this selection bias problem lead to biased estimates of park effectiveness (for example: Bruner et al. 2001; Naughton-Treves et al. 2005; Gaveau et al. 2007). When characteristics that influence the location of protected areas are accounted for, the impact of parks on deforestation is reduced by more than half (Andam et al. 2008; Joppa and Pfaff 2011).

Matching protected areas to locations with similar characteristics is one way to account for the non-random placement of protected areas (Andam et al. 2008; Pfaff et al. 2009; Joppa and Pfaff 2010; Joppa and Pfaff 2011). Observable characteristics expected to influence the likelihood that an area is protected include measures of economic potential of the land, such as distance to roads or cities and slope or elevation (Joppa and Pfaff 2009). Matching methods find the observation most like the park based on these observable characteristics, and thus create an "apples to apples" comparison. However, matching estimators can still result in biased estimates of impact if there are unobservables correlated with both the placement of the protected area and the outcome. One way to reduce errors from hidden bias is to combine matching with panel regression, since panel regression controls for time-invariant unobservables.

Methods

Study Area

Our study area covered 17 federally protected areas in Central Russia (Figure 11). There were three different types of parks within the study area: strict protected areas ('zapovedniks'), national parks, and nature reserves ('zakazniks'); these are described in more detail below. There were eight zapovedniks, four national parks, and three zakazniks, and together, these parks covered a total area of approximately 6,200 km^2. The date of establishment of these protected areas varied across the sample: six were established before the collapse of the Soviet Union and 11 after. The oldest protected area in our sample was established in 1935 and the most recent in 2006. Eight Landsat footprints were used to measure forest disturbance inside and outside of the parks (shown in Figure 11).

Central Russia is a mosaic of agriculture and forest. Agricultural crops include mostly grains, and the southern part of the study area includes the fertile 'black soil' zone. The forests of Central Russia are made up of deciduous and mixed tree species. Common deciduous species include lime, oak, birch, aspen, ash, maple, and elm. Scotch pine is the dominant coniferous species. While total forest cover is lower in this region than parts of Northern European Russia, timber harvesting is still important due to low transportation costs. In particular, timber harvesting around Moscow city has increased considerably since 2000 (Wendland et al., *submitted*). Population density in Central Russia is also higher than in other parts of Russia.

Protected Areas in Russia

Zapovedniks, national parks, and federal zakazniks cover about three percent of Russia, or 54 million hectares (Krever et al. 2009). Zapovedniks are strict nature reserves: equivalent to an IUCN designation of Category I protected area. While there are limited use zones within some zapovedniks, the primary purpose of these protected areas is scientific research (Wells and Williams 1998). The first zapovednik was established in the early 1900s and the system of zapovedniks has been extended and consolidated several times since in Russia. At least a dozen new zapovedniks have been established in Russia since the collapse of the Soviet Union (Krever et al. 2009).

Zapovedniks tend to be well funded and staffed compared to other types of protected areas; however, this financing is still inadequate to cover many of the costs of the parks (Wells and Williams 1998). Zapovedniks are managed by the Ministry of Environmental Protection and Natural Resources in Russia. Since there is no permitted logging within zapovedniks, evidence of logging within these protected areas is indicative of illegal activity.

National parks are a more recent designation in Russia; the first national park was created in 1983 and more than a dozen have been created since the collapse of the Soviet Union (Krever et al. 2009). National parks were created to provide recreational and environmental education opportunities for people, and tend to be larger than other types of protected areas in Russia. They correspond to an IUCN Category II or V protected area, depending on the allowed activities. There is designated federal funding for national parks; however, budgets vary considerably across parks. The Federal Forest Service managed national parks until 2000, which created several conflicts between intended and realized uses within the parks since the primary mission of the Forest Service is industrial logging. Since 2000, National Parks have been managed by the Ministry of Environmental Protection and Natural Resources (Ostergren and Jacques 2002). However, permits for logging within National Parks are still granted on a case-by-case basis (Laestidius, personal communication). Thus, evidence of logging within national parks is not necessarily evidence of illegal activity, but it is indicative of the level of contribution of national parks to providing recreational opportunities and biodiversity conservation in European Russia.

Federal zakazniks are one of the oldest forms of protection in Russia and correspond to an IUCN Category IV or V protected area. Several limited uses are allowed within federal zakazniks, such as grazing, hunting and fishing. There is also an extensive network of regional zakazniks, which are funded and managed at the regional level. We do not include regional zakazniks in our analysis. While there is no set management entity for federal zakazniks, the Ministry of Agriculture oversees many of them (Ostergren and Jacques 2002). Federal funding tends to be more limited for zakazniks compared to the other two types of federally protected areas considered in this study, which impacts staffing and enforcement (Pryde 1997). It is difficult to classify whether logging is legal or illegal within zakazniks, since logging permits can be granted, but the lack of monitoring and enforcement also means that illegal harvesting is likely (Dubinin, personal communication). Thus, of the three types of federally protected areas we expected that logging would be most prevalent within federal zakazniks.

Data

Data on logging within protected and unprotected areas was available from a remote sensing classification of forest disturbance in European Russia (Baumann et al., *in preparation*). Land was classified as forested or non-forested in 5-year intervals between 1985 and 2010. For our analysis we randomly sampled 10,000 forested pixels – 30 m^2 plots, or the smallest mappable unit – from each of the eight Landsat footprints using the 1985 land cover classes; this gave a sample size of 80,000 pixels. For each pixel, we recorded whether it stayed in forest over each 5-year period as a value of "0" and whether it transitioned from forest to non-forest as a value of "1". A pixel was removed from the dataset once the forest was cut.

Of the sampled pixels, about 1,000 were protected in the 1985-1990 time period and about 3,000 were protected in the 2005-2010 time period (Table 11). The number of protected pixels changes over time because the total number of protected areas was changing and because once a pixel becomes non-forest, we removed it from the dataset. Since this left close to 77,000 unprotected pixels we randomly selected 10,000 pixels to serve as control observations. Since a few of these were outside of Russia's national boundary, they were deleted, leaving 9,986 unmatched control observations in 1985 (Table 11). While increasing the number of controls provides more opportunities for "good" matches, there is a tradeoff with computation time. Previous studies of park effectiveness use a control size two to four times that of the protected area sample. Because pixels are removed from the dataset once they are cut, the total number of unmatched control pixels also varies over time (Table 11).

For each pixel we calculated measures of observable characteristics that would influence the probability that the pixel was protected or the probability that forest was cut. These observable characteristics included: the distance to forest edge, closest town, urban centers (either Moscow or St. Petersburg), and closest road, as well as the elevation, slope and presence of evergreen species in the pixel. We measured each variable in ArcGIS. Distances were measured as the Euclidean distance from the pixel to the object and recorded in kilometers. Datasets on Russian cities and roads are circa 1990 and were provided by Russian partners. Elevation data come from USGS's Global Digital Elevation Model and were measured in meters. Slope data come from NOAA's Global Land 1-km Base Elevation Project and were measured as a percent. The presence of evergreen trees is recorded as a binary variable and was derived from Moderate Resolution Imaging Spectroradiometer imagery data. Each independent variable was standardized to range between zero and one to facilitate estimation of the binary regression models (Table 12). All independent variables, except distance to forest edge, are time-invariant.

In addition to these observable variables we also recorded the administrative region for each pixel to use in estimation equations. Including regional dummy variables in regression helps minimize unobservables correlated with the treatment and outcome variables. Regional differences in state capacity and enforcement influence timber harvesting in Russia (Wendland et al., *submitted*; Wendland et al., *in preparation*). Regional differences could also influence the probability that an observation was protected; for example, some leaders might be more willing to have a new protected area designated in their region than others.

Analysis

To measure park effectiveness we used a combination of methods: first we used matching to create an "apples to apples" comparison and estimated the average effect of protected areas on logging using matching metrics; second, we used cross-sectional and panel binary regression analysis on our matched sample. For both methods we were interested in calculating the average treatment effect on the treated (i.e., protected areas), or:

$$\tau = \frac{1}{N}\sum_{1,Pi=1}^{N} L_i(1) - L_i(0), \quad (1)$$

where $P_i = 1$ when a pixel, *i*, is protected and $L_i(.)$ is the observed outcome with "1" indicating logging and "0" otherwise. This gives the amount of logging prevented within the boundaries of the parks by protected area status. We estimated treatment effects separately for each type of protected area, i.e., zapovedniks, national parks, and federal zakazniks.

We used two methods to match protected areas to control groups. First, we matched on the propensity score, where the propensity score is the estimated probability of receiving treatment based on a set of variables selected by the researcher (Rosenbaum and Rubin 1983; Becker and Ichino 2002; Caliedno and Kopeinig 2008). The propensity score equation should include variables that influence both the treatment and the outcome variable (Caliendo and Kopeinig 2008). To estimate the probability of being protected we used a cross-sectional logit model:

$$\text{Prob}(P_i = 1) = \frac{e^{\alpha+\beta X_i+\omega REGION_i}}{1+e^{\alpha+\beta X_i+\omega REGION_i}}, \quad (2)$$

where X_i is a matrix of pixel-level observables described in the data section and Table 12, and $REGION_i$ is a matrix of region dummy variables.

After generating a propensity score for each treatment and control observation, we used several matching metrics to estimate τ: nearest neighbor, radius, and kernel matching. Nearest-neighbor uses a minimum linear distance to match treated and control observations; radius matching pairs treated observations to control observations that fall within a specified radius; and kernel matching uses a weighted average of all individuals in the control group to estimate the treatment effect (Caliendo and Kopeinig 2008). For several metrics we restricted the matched samples using common support and calipers; this ensures results are based on the best matches. Common support drops treatment observations with a propensity score higher than the maximum or less than the minimum propensity score of the controls and calipers restricts the maximum distance between the propensity score of the treated and control observations.

As an alternative to propensity score matching we matched using the Mahalanobis-metric. The Mahalanobis-metric is a distance-based matching estimator that allows correlation between covariates (Caliendo and Kopeinig 2008). It selects the control unit with the minimum distance to the treatment based on a specified set of covariates. We used the covariates in X_i for matching with the Mahalanobis-metric and used calipers. All matching estimators were implemented using Leuven and Sianesi's (2003) program *psmatch2* in Stata 11. While standard errors on propensity score matching are inefficient due to first-stage estimation of the propensity score (Abadie and Imbens 2009), the Mahalanobis-metric provides analytical standard errors following Abadie and Imbens (2006).

Matching should improve the covariate balance between protected and control observations. To check covariate balance for our independent variables, X_{it}, we calculated the normalized difference in means before and after matching following Imbens and Woolridge (2009). Normalized difference in means is estimated as the difference in the average covariate values normalized by the square root of the sum of the treatment and control group variances. This estimate is considered a better measure of differences in covariates across treatment and control groups than measures that do not take into account large differences in the number of treatment and control observations (Imbens and Woolridge 2009). In general, a normalized difference greater than one standard deviation is considered 'large'.

Since matching only controls for observable characteristics, we used Rosenbaum bounds to test the sensitivity of our results to hidden bias. Rosenbaum bounds report the amount of hidden bias that would have to be present to undermine the estimated treatment effect (Becker and Caliendo 2007). For binary outcomes, the Mantel-Haenszel statistic is calculated. The higher the level of bias that can be present without changing the estimated results, the more likely the reported treatment effect is insensitive to unobservables.

Next, we combined matching with regression analysis to provide a more robust estimate of protected area effectiveness (Imbens and Woolridge 2009). We estimated both logistic and linear probability models; the former takes into account the non-linearity in the dependent variable while the latter is easier to interpret and compare to matching metrics. To create a matched sample for regression analysis we followed Rubin (2006) and ordered protected areas by their propensity score values and matched treatment and control observations using one-to-one matching without replacement. For cross-sectional analysis we used the matched sample for that time period and estimated the following regression:

$$\text{Prob}(L_i = 1) = \alpha + \beta X_i + \delta P_i + \omega REGION_i + \varepsilon_i, \quad (3)$$

where the error term, ε_i, is modeled as a binomially distributed random variable in the logit model and a normally distributed random variable in the linear probability model. The marginal effect of δ from both the logit and linear probability models gives the treatment effect, similar to τ in Equation

1. Post-matching, cross-sectional regressions are recommended when matching fails to provide complete balance in the underlying covariates.

Additionally, we used the matched sample to run panel regression analysis since we have data over multiple time periods. Panel regression controls for time-invariant unobservables that could be correlated with the treatment and outcome; thus, it helps relax the assumption in matching of no hidden bias. To create a matched, panel dataset, we matched treatment to control observations in 1985, when all observations were in forest. We used the one-to-one matching method described above. We then reshaped our data and estimated the following equation using both the logit and linear probability models:

$$\text{Prob}(L_{it} = 1|\alpha_i) = \alpha_i + \beta X_{it} + \delta P_{it} + \omega REGION_i + \gamma YEAR_t + \varepsilon_{it}, \quad (4)$$

where α_i are pixel-specific effect, $YEAR_t$ is a matrix of year fixed effects used to control for variations over time that affected all observations, and ε_{it} is modeled as discussed above.

The estimated parameter, δ, can be used to calculate the overall impact of protected areas for the 25-year study period and year-specific effects for protected areas can be obtained by interacting P_{it} with $YEAR_t$. Coefficients are reported for δ and interactions between P_{it} and $YEAR_t$ from logit and linear probability models to compare the direction of influence (i.e., positive or negative) of protected areas on logging. However, only the linear probability model can be used to estimate the marginal effect for δ or for interactions between P_{it} and $YEAR_t$, giving the average treatment effect in Equation 1. In panel logit models, α_i is eliminated from estimation, preventing consistent estimation of the marginal effects (Cameron and Trivedi 2009). Marginal effects from the linear probability model were used to compare the estimated effect of protected areas using matching metrics and post-matching regression analysis.

We estimated pixel-specific effects, α_i, in Equation 4 as both random and fixed effects. Modeling α_i as random effects can lead to biased estimates if α_i is correlated with the error term. Modeling α_i as fixed effects gives a more consistent estimate since it allows correlations between α_i and the error term, which could have occurred if unobservables were correlated with the decision to create a protected area and to cut timber. Since the number of protected observations varies over time (Table 11), δ can be estimated using fixed effects. However, in the logit specification, a major limitation of the fixed effects model is that any observation that does not experience an outcome of "1" over the sum of the time periods is dropped in estimation, which can lead to a considerable loss of observations (Cameron and Trivedi 2009). The linear probability model allows all observations to be used in both random and fixed effects estimation.

Results

Comparing percent harvested across the unmatched sample suggested that rates of logging were higher within protected areas for many time periods (Figure 12). Zakazniks, in particular, showed high rates of forest disturbance. There are temporal trends in the overall percent logged: disturbance was high between 1985 and 1995, corresponding to the period right before and after the collapse of the Soviet Union. Harvesting decreased in the late 1990s, which is consistent with other findings on timber harvesting in post-Soviet Russia (Torniainen et al. 2006). Timber harvesting increased again both inside and outside of protected areas in 2000-2005. This period was also a time of marked economic and political change in Russia: overall economic growth increased rapidly after the Asian financial crisis ended in 1998 and Vladimir Putin assumed the presidency in 2001.

However, these results do not take into account the non-random placement of parks, which are large (Table 13). The location of each type of protected area differed from control observations in our sample, and the influence of particular covariates was not always the same across park types.

For example, in 1995, zapovedniks were more likely to be located farther from a town and road, and at steeper slopes, than control observations, but were closer to large urban areas and at lower elevations. National parks were more similar to control observations, but still differed in distance to towns and major urban areas, and were found at lower elevations and less steep slopes. Federal zakazniks were also found at lower elevations and less steep slopes, and were, on average, closer to the forest edge than control observations. Results from 1995-2000 were shown since this was the first time period where all types of protected areas appeared in the sample (Table 11), but results were similar for other time periods. Normalized differences in means also indicated large differences between protected areas and control observations in the unmatched sample (Table 14), with several differences larger than one standard deviation of the independent variables (Table 12, Column 2).

The estimated average treatment effects for protected areas showed some consistency across matching estimators (Table 15). These values can be interpreted as the proportion of logging prevented by protected status, so in Column 2, using one-to-one nearest neighbor matching, zapovedniks were effective at curtailing 3.3 percent of logging that would have occurred within the sample of pixels in 1985-1990. Based on the 729 pixels that were in the zapovednik sample in 1985-1990, this 3.3 percent treatment effect translates into 24 pixels that were not deforested due to protection. The average treatment effect for zapovedniks was statistically significant across all estimators in all time periods. The treatment effect for national parks and federal zakazniks varied across time periods, and also across estimators. The number of treatment and control observations used to estimate these treatment effects varied across samples and time (Table 11). For one-to-one matching all treatment observations were matched to exactly one control observation. For estimators using common support, ten percent of the treatment observations were dropped. The remaining treatment observations were then matched to one control observation, except in the case where we used five matches.

Matching greatly improved covariate balance for all protected area types: normalized differences in means were all less than one standard deviation in the matched samples (Table 14). Results are presented for one-to-one nearest neighbor matching without replacement since this is what was used for post-matching regression, and overall, this resulted in the best covariate match. However, differences still remained between protected and matched control observations (i.e., the normalized difference in means is not zero), indicating that post-matching regression would provide a more robust estimate of the causal effect of protected areas.

For each matching metric in Table 15 we checked the Mantel-Haenszel test statistic for hidden bias (unreported in the table). For all protected areas and metrics we found that a relatively small amount of hidden bias would alter the estimated treatment effect. On average, the treatment effects were sensitive to an unobserved variable that would double the odds that the observation was protected. While this does not mean that there were unobservables confounding the estimates, this is a relatively low sensitivity to hidden bias, and cautions against using the matching estimators by themselves.

Turning to post-matching regressions, in most cases the direction of impact (i.e., positive or negative) of protected areas on logging was similar across logistic and linear probability regression models (Table 16). There were some differences in sign and statistical significance across estimators and samples. Similar to matching, results were most consistent across estimators and samples for zapovedniks.

For zapovedniks, the overall effect for the 25-year study period was negative when pixel-specific effects were modeled as random effects; with fixed effects the statistical effect was weaker. The sign and statistical significance of year-specific effects were more variable. In general, after 1995, all specifications and models showed a statistically significant and negative effect of zapovedniks on logging, indicating that zapovedniks were successful at preventing logging within their boundaries during these periods. However, results for 1985-1990 and 1990-1995 from the most robust specification – fixed effects – suggest that zapovedniks that existed during these periods were not effective at preventing logging. In fact, in 1985-1990, zapovedniks experienced more logging than matched control observations.

The 25-year impact of national parks or zakazniks on logging was not statistically significant using either random or fixed effects. Year-specific effects for national parks were consistent across all samples and models. In general, national parks did not prevent logging compared to similar control observations. Year-specific effects for federal zakazniks varied the most across samples and models, and very few results were consistently statistically different from zero. There was some weak indication that zakazniks prevented logging in 1985-1990 and 1995-2000 relative to similar control observations using cross-sectional and random effects specifications, but when fixed effects were included this impact was no longer statistically significant. Similarly, cross-section and random effects specifications suggest zakazniks experienced more logging in 1995-2000 than control observations, but not when fixed effects were used. None of the samples or models found a statistical difference between zakazniks and control observations after 2000.

When we compared average treatment effects using the one-to-one matches with post-matching linear probability regression, we found some consistency in the sign and size of the estimated impact of protected areas on logging (Table 17). Since standard errors are not correctly estimated using propensity score matching (Abadie and Imbens 2009), statistical significance using the post-matching linear probably model is the more robust measure. The major difference that appeared in comparing average treatment effects across estimators was the estimated effect of zapovedniks in the 1985-1990 and 1990-1995 periods. Similar to the regressions results, the panel models, and particularly the fixed effects specification, suggested a different effect of zapovedniks on logging than the other estimators. The magnitude of the effect also varied across some estimators and time periods, suggesting that controlling for time-invariant unobservables using panel regression controlled some degree of hidden bias in our sample. Estimated treatment effects represent the absolute change observed from having protected areas; their small values reflect, in part, the small number of pixels that experienced forest disturbance within the study area (Table 11).

Discussion

Protected areas in our study had different observable characteristics than areas outside of parks, and comparing parks to non-parks would have resulted in biased estimates of the impact of protected areas on preventing logging. Surprisingly, protected areas in Russia had many characteristics that suggested they were placed in relatively high threat areas: they were closer to major urban areas, had lower elevations, and less steep slopes than control observations. This is not typical of many protected areas (Andam et al. 2008; Joppa and Pfaff 2009), and suggests that the impact these parks could have on providing biodiversity conservation and ecosystem services is high (Joppa and Pfaff 2011).

To account for selection bias, we measured park effectiveness using matching and post-matching regression. Unlike previous analyses of the impact of protected areas, we also used panel regression to control for time-invariant hidden bias. Combining matching and regression can provide a more robust estimate of causal impacts (Imbens and Woolridge 2009), and for our sample, we found that matching by itself did not completely balance covariates and was sensitive to small changes in hidden bias. When we combined matching with regression analysis we found consistent estimates across cross-sectional, random and fixed effects models for most parks and time periods. However, some differences remained between cross-sectional and random effects models versus fixed effects models. Fixed effects models are more robust because they control for omitted variables that are correlated with the placement of the park and the decision to cut timber. Unobservables might be especially likely during a transition period, such as the one experienced right before and after the collapse of the Soviet Union, and our results suggested that using fixed effects does control for unobservables related to park placement and timber harvesting in these periods for zapovedniks.

Based on our estimated treatment effects, strict protected areas – zapovedniks – were the only type of park successful at preventing logging in Russia. The effect over the entire 25-year time period was negative but only statistically significant using random effects. Year-specific effects indicated that the impact of zapovedniks varied throughout the collapse of the Soviet Union. Right before and after the transition, zapovedniks had no statistical effect on preventing logging within their boundaries. Only when stability returned to Russia in the late 1990s did these parks prevent illegal logging. The estimated impact of zapovedniks after 1995 was still low, at about two percent in each of these 5-year time periods. A two percent treatment effect is slightly smaller than the treatment effect estimated for global protected areas, which is around three to eight percent, and for protected areas in Costa Rica, which is around 11 percent (Andam et al. 2008; Joppa and Pfaff 2011). Part of the reason for these low treatment effects is that threats to protected areas were low, or that, at least our sample, the overall probability of logging was low.

National parks and federal zakazniks fared worse. They experienced rates of logging similar to areas outside of protected areas. The overall effect of these parks was not different from zero at the 90 percent confidence level and no year-specific effects were consistently significant across estimators. In general, there was more variation in estimated impacts for these types of parks than for zapovedniks; one reason for this might be the larger variations in park-specific budgets and enforcement outside of strict protected areas. Logging within these two types of parks may be legally permitted, and so we cannot conclude that we have detected illegal activity by finding no impact of these protected areas on preventing forest cover loss. However, the fact that there was no statistical difference between the parks and control observations raises questions about their effectiveness at providing recreational and education opportunities for local people and biodiversity conservation for society at large.

These findings have important implications for measuring conservation effectiveness and for understanding the impact of non-violent political and socioeconomic changes on protected areas. In terms of measuring conservation impact, our paper adds to a growing literature on the importance of accounting for selection bias when measuring the effectiveness of protected areas (Mas 2005; Andam et al. 2009; Pfaff et al. 2009; Joppa and Pfaff 2010). With the continued expansion of global protected areas (Jenkins and Joppa 2009), understanding where parks can provide the most impact will be necessary to prioritize placement (Joppa and Pfaff 2011). Using rigorous impact methods to measure conservation effectiveness is a relatively new field (Ferraro and Pattanayak 2006; Ferraro 2009), but one with major policy implications given the emphasis on causal outcomes in payments for ecosystem services programs. Matching by itself may not always be the best measure of effectiveness because it assumes no hidden bias. Combining matching with panel regression can minimize errors due to unobservables, which may be especially prominent during periods of instability and transition.

For conservation in Russia, our results suggest that strict protected areas have prevented logging within their boundaries since 1995, but that other types of protected areas are contributing little to biodiversity protection since the collapse of the Soviet Union. This is important in light of a recent GAP analysis for conservation in Russia that calls for the creation of an additional 403 federally protected areas (Krever et al. 2009), with federal zakazniks making up the majority of the proposed parks. Our analysis raises questions whether new protected areas would be able to prevent biodiversity loss given that current protected areas, with the exception of zapovedniks, seem to have had little effect on forest cover. Understanding why these parks had so little effect would be important to know before future parks are created. Additionally, a rapid increase in the number of protected areas occurred in other post-Soviet countries as well. Based on the results from our analysis, the question arises whether or not this increase in globally protected areas due to the collapse of the Soviet Union (Radeloff et al., *in preparation*) is having a meaningful impact on biodiversity conservation.

For the global conservation community, protected areas, and thus biodiversity conservation, are impacted during times of non-violent societal upheaval. Similar to the impacts of war on biodiversity, the effects of non-violent change are not always clear *a priori*, as some of the land use changes in former Soviet Bloc countries had positive impacts for wildlife and conservation. However, the cornerstone for biodiversity conservation, protected areas, appear to have been exploited in Russia during the instability and chaos that surrounded the collapse of the Soviet Union. The collapse of the Soviet Union was not the last major political and socioeconomic change to occur (Henry and Springborg 2010), and it can take many years for a country to recover from these non-violent upheavals. Similar to periods of war, the global community may need to provide assistance to protected areas during these transition periods if biodiversity and ecosystem service conservation are to remain effective.

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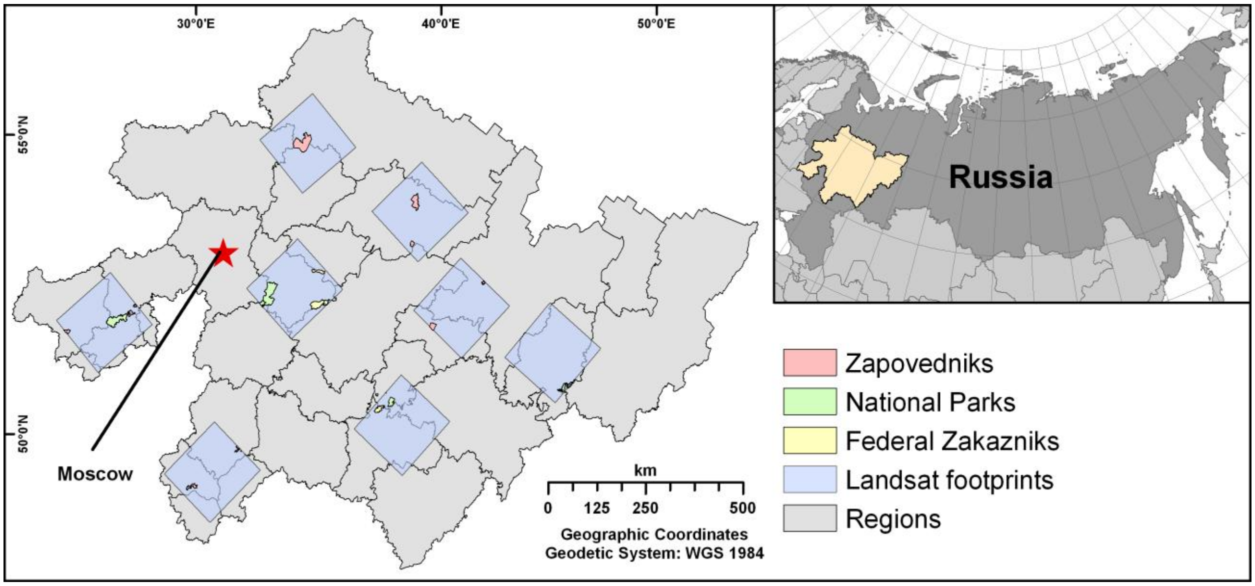

Figure 11: Location of protected areas and satellite images in study area in European Russia

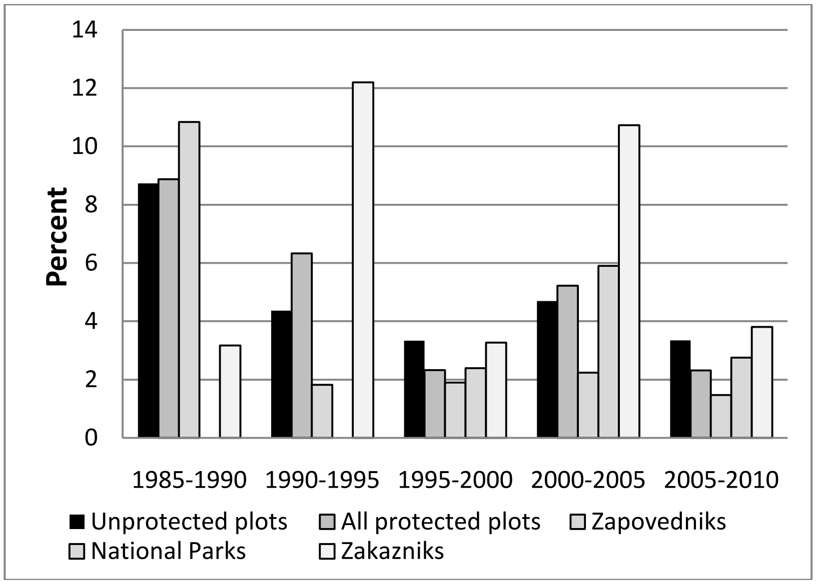

Figure 12: Percent of forest disturbance in observations by year and type for unmatched sample

Table 11: Number of observations by year and protected area type in unmatched and matched samples

	1985-1990	1990-1995	1995-2000	2000-2005	2005-2010
Unmatched Controls					
Total pixels	9,986	9,024	8,626	8,398	8,115
Pixels logged	898	381	208	305	211
Zapovedniks					
Total pixels	729	712	1,122	1,114	1,300
Pixels logged	79	13	11	21	6
Parks	2	3	7	7	8
Zapovednik Matched Controls[a]					
Total pixels	729	712	1,122	1,114	1,300
Pixels logged	103	54	31	53	33
National Parks					
Total pixels	0	0	986	1,006	949
Pixels logged	0	0	21	56	19
Parks	0	0	4	5	5
National Park Matched Controls[a]					
Total pixels	0	0	986	1,006	949
Pixels logged	0	0	31	35	26
Federal Zakazniks					
Total pixels	252	548	481	464	426
Pixels logged	8	67	16	45	13
Parks	2	3	3	4	4
Federal Zakaznik Matched Controls[a]					

Total pixels	252	548	481	464	426
Pixels logged	31	40	22	39	12

[a]Matched controls are from one-to-one nearest neighbor matching without replacement.

Table 12: Summary statistics by type of observation over all years[a]

Variable	All Observations	Controls	Zapovedniks	National Parks	Federal Zakazniks
	Mean (Std dev)	Mean (Std dev)	Mean (Std dev)	Mean (Std dev)	Mean (Std dev)
Distance to forest edge	0.083 (0.095)	0.082 (0.093)	0.102 (0.115)	0.092 (0.094)	0.051 (0.052)
Distance to closest town	0.311 (0.200)	0.324 (0.210)	0.214 (0.148)	0.279 (0.068)	0.261 (0.129)
Distance to major urban center	0.483 (0.204)	0.495 (0.209)	0.480 (0.110)	0.331 (0.203)	0.427 (0.150)
Distance to closest road	0.121 (0.107)	0.113 (0.100)	0.211 (0.141)	0.092 (0.077)	0.127 (0.091)
Elevation	0.457 (0.136)	0.471 (0.132)	0.355 (0.123)	0.487 (0.113)	0.340 (0.127)
Slope	0.057 (0.067)	0.058 (0.067)	0.057 (0.076)	0.048 (0.056)	0.055 (0.062)
Evergreen tree species	0.034 (0.182)	0.035 (0.184)	0.021 (0.142)	0.037 (0.189)	0.047 (0.212)
Observations	54,238	44,149	4,977	2,941	2,171

[a]Standardized normal values, range 0-1; averages are over all five time periods.

Table 13: Cross-sectional logit regression of the probability of protection (Equation 2) for 1995-2000 [a]

Variable	Prob(Zapovedniks=1)	Prob(National Parks=1)	Prob(Federal Zakazniks=1)
	Coefficient (Std Error)	Coefficient (Std Error)	Coefficient (Std Error)
Distance to forest edge	4.470*** (0.344)	0.468 (0.703)	-6.646*** (1.197)
Distance to closest town	2.135*** (0.449)	12.409*** (0.910)	11.424*** (0.850)
Distance to major urban center	-7.247*** (1.136)	-49.855*** (2.887)	-3.936*** (1.348)
Distance to closest road	5.805*** (0.386)	-0.661 (0.848)	2.138** (0.827)
Elevation	-15.796*** (0.839)	-4.493*** (1.092)	-10.141*** (0.532)
Slope	2.770*** (0.691)	-7.941*** (1.195)	-1.443* (0.843)
Evergreen tree species	0.304 (0.291)	0.208 (0.250)	0.141 (0.310)
Regional Fixed Effects	Yes	Yes	Yes
Observations	5,323	3,282	2,169

*** p<0.01, ** p<0.05, * p<0.1

[a]The dependent variable was the probability of protected status. A cross-sectional logit model using robust standard errors was estimated. Results for 1995-2000 are shown since this was the first time period where all types of protected areas appear in our sample; results for other time periods are available by request.

Table 14: Normalized difference in means for unmatched and matched samples[a]

Variable	Zapovedniks versus Controls		National Parks versus Controls		Federal Zakazniks versus Controls	
	Unmatched	**Matched**	**Unmatched**	**Matched**	**Unmatched**	**Matched**
Distance to forest edge	0.09	-0.03	-0.13	0.03	-0.11	0.03
Distance to closest town	-0.12	-0.07	-0.19	0.06	-0.17	0.14
Distance to major urban center	-0.13	0.03	-0.57	-0.02	-0.24	-0.04
Distance to closest road	0.50	0.02	-0.14	-0.002	0.12	0.001
Elevation	-0.42	-0.08	0.06	0.02	-0.65	-0.02
Slope	-0.03	-0.002	-0.11	0.02	-0.01	-0.06
Evergreen tree species	-0.08	-0.02	-0.01	-0.01	0.03	0.03

[a]Unmatched sample included all control observations for that time period. Matched sample was based on one-to-one matching without replacement.

Table 15: Average treatment effects for protected areas using matching metrics[a]

	Matching on the Propensity Score				Matching without the Propensity Score
	Nearest neighbor [1 neighbor] without replacement	Nearest neighbor [5 neighbors] with common support	Radius with caliper and common support	Kernel density with common support	Mahalanobis with caliper
Zapovedniks 1985-1990	-3.3%**	-8.2%***	-5.2%***	-7.8%***	-7.4%**
Zapovedniks 1990-1995	-5.4%***	-6.8%***	-3.1%***	-2.5**	-3.8%**
Zapovedniks 1995-2000	-1.8%***	-1.8%***	-1.5%***	-1.3**	-1.8%*
Zapovedniks 2000-2005	-3.4%***	-3.2%***	-2.0%***	-3.3%***	-3.0%**
Zapovedniks 2005-2010	-1.7%***	-1.6%***	-4.2%***	-3.5%***	-4.3%***
National Parks 1995-2000	-2.0%***	-2.2%*	-2.8%***	-3.4%***	-3.0%***
National Parks 2000-2005	2.3%**	1.8%**	0.9%	0.9%	1.0%
National Parks 2005-2010	-0.5%	-0.2%	-0.6%	-0.3%	-0.1%
Federal Zakazniks 1985-1990	-9.1%***	NA[b]	NA[b]	NA[b]	1.6%
Federal Zakazniks 1990-1995	5.0%***	1.5%	4.8%***	2.7%	1.8%
Federal Zakazniks 1995-2000	-2.4%**	-1.3%	-3.0%***	-1.1%	-1.1%
Federal Zakazniks 2000-2005	0.3%	4.4%	3.4%**	3.5%	-1.7%
Federal Zakazniks 2005-2010	-2.6%**	-4.5%**	-0.2%	-3.0%	0%

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

[a]One-to-one nearest neighbor matching without replacement used all treatment observations. The remaining matching metrics used common support and or calipers to estimate the treatment effect based on the best matches. Thus, total number of treatment and control observations varied according to number of treatment observations dropped.

[b]No observations within common support.

Table 16: Coefficients for protected status from logit and linear probability models using the matched sample[a]

	Logit Regression			Linear Probability Model		
	Cross-sectional	**Random effects**	**Fixed effects**	**Cross-sectional**	**Random effects**	**Fixed effects**
Zapovedniks		-0.809***	-0.493*		-0.017***	-0.004
National Parks		0.152	0.114		0.005	0.004
Federal Zakazniks		-0.133	0.089		-0.009	0.001
Zapovedniks 1985-1990	-0.286	-0.003	1.195***	-0.034	0.022*	0.051***
Zapovedniks 1990-1995	-0.804*	-1.1087***	0.808	-0.022*	-0.023***	0.006
Zapovedniks 1995-2000	-0.950***	-1.233***	-1.090***	-0.028**	-0.025***	-0.018**
Zapovedniks 2000-2005	-0.866**	-1.080***	-0.749**	-0.025**	-0.027***	-0.016**
Zapovedniks 2005-2010	-1.035***	-1.399***	-1.526***	-0.019**	-0.023***	-0.022***
Observations	*Varied*	*13,917*	*1,506*	*Varied*	*13,917*	*13,917*
National Parks 1995-2000	-0.301	-0.337	-0.288	-0.013	-0.009	-0.008
National Parks 2000-2005	0.380	0.484**	0.402	0.023	0.020*	0.017
National Parks 2005-2010	0.118	0.094	0.126	0.004	0.002	0.002
Observations	*Varied*	*10,553*	*1,303*	*Varied*	*10,553*	*10,553*
Federal Zakazniks 1985-1990	-0.514	-1.397***	-0.828	-0.031	-0.078***	-0.036*
Federal Zakazniks 1990-1995	0.201	0.606**	0.700	0.021	0.051**	0.046**

Federal Zakazniks 1995-2000	-1.060***	-0.802**	-0.188	-0.061**	-0.034**	-0.011
Federal Zakazniks 2000-2005	-0.227	0.357	0.507	-0.025	0.027	0.030
Federal Zakazniks 2005-2010	-0.489	-0.299	0.011	-0.023	-0.010	0.002
Observations	*Varied*	*5,143*	*1,153*	*Varied*	*5,143*	*5,143*

*** p<0.01, ** p<0.05, * p<0.1

[a]Dependent variable was the probability of logging. Cross-sectional results are based on estimation of Equation 3 and used robust standard errors. The cross-sectional model is estimated for each year and so the total number of observations varied. Panel regression results are based on estimation of Equation 4; the models were estimated for each park type and its matched control observations. Robust standard errors were used in the linear probability model.

Table 17: Comparison of average treatment effects for protected areas across matching and post-matching linear probability regression

	Matching	Post-Matching Linear Probability Model		
	Nearest neighbor [1 neighbor] without replacement	Cross-sectional	Random effects	Fixed effects
Zapovedniks 1985-1990	-3.3%***	-3.4%	2.2%*	5.1%***
Zapovedniks 1990-1995	-5.4%***	-2.2%*	-2.3%***	0.6%
Zapovedniks 1995-2000	-1.8%***	-2.8%**	-2.5%***	-1.8%**
Zapovedniks 2000-2005	-3.4%***	-2.5%**	-2.7%***	-1.6%*
Zapovedniks 2005-2010	-1.7%***	-1.9%**	-2.3%***	-2.2%***
National Parks 1995-2000	-2.0%***	-1.3%	-0.9%	-0.8%
National Parks 2000-2005	2.3%**	2.3%	2.0%*	1.7%
National Parks 2005-2010	-0.5%	0.4%	0.2%	0.2%
Federal Zakazniks 1985-1990	-9.1%***	-3.1%	-7.8%***	-3.6%*
Federal Zakazniks 1990-1995	5.0%***	2.1%	5.1%**	4.6%**
Federal Zakazniks 1995-2000	-2.4%**	-6.1%**	-3.5%**	-1.1%
Federal Zakazniks 2000-2005	2.3%	-2.5%	2.7%	3.0%
Federal Zakazniks 2005-2010	-2.6%**	-2.3%	-0.9%	0.1%