Modeling of Logging Industry Dynamics Under the Global Climate Change: the Evidence from Siberian Regions

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Abstract. As a part of global economy, forestry experiences influence of diverse factors and global climate change in particular, which can affect forestry directly or indirectly via changes in qualitative and quantitative assessment of forest growing stocks, and in positive or negative manner. Climate change effects on Russian forestry are still poorly studied and call for more attention in policy-making. One of the direct impacts is shortening of winter logging season duration, which may result in decreasing wood harvests. Using the data on logging volumes in Krasnoyarsk Krai and Irkutsk Oblast and estimated duration of winter logging season on meteorological stations for the retrospective period of 1966-2018, eight ARDL models were evaluated. The modeling results supported the idea of dependence of harvested wood volumes on winter logging season duration across all considered meteorological stations. To reduce negative impacts on logging industry in terms of wood harvest reduction, adaptation activities in forestry are sorely needed.

Research area: economics and national economy management.

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Introduction

Climate change challenge is now becoming a very important topic. Over the last six decades global mean air temperature reached unprecedented growth rates and this tendency is likely to persist then in future (IPCC, 2014). It is notable that on the territory of Russia there has been more than a two-fold increase of average air temperature: 0.47 °C against 0.18 °C per decade (Roshydromet, 2020).

Climate change is closely connected to economy and considerably influences it, so there is a growing body of academic literature on diverse economic effects of warming. For example, temperature and precipitation alterations results in diseases outbreaks among population that reduces economically active population – workforce and GDP level as well (Bosello et al., 2006). Another set of impacts covers changes in energy consumption, fishery, agricultural sector, forestry (Tol, 2009) and natural disasters causing significant damage to infrastructure and material assets (Porfiriev, 2015). Climate change is able to exacerbate some other global challenges, e.g. inequality and poverty by slowing down economic growth of agriculture-dependent developing economies in low-income southern regions where energy demand for cooling will tend to increase in near future (Rehdanz and Maddison, 2005; Dell et al., 2008; Maddison, 2003). Conversely, high-latitude developed countries will benefit from changing climate due to shortening of heating season and decreasing costs for heating services (Labriet et al., 2015).

Being one of the major parts of the global economy, forestry experiences diverse effects: institutional factors, macroeconomic environment and climate change along with its consequences. Climate change can affect forest industry directly or indirectly via changes in qualitative and quantitative assessment of forest growing stocks, and in positive or negative manner.

Since forest is considered as a renewable resource and an important carbon depositor in climate system regulation (Svidenko and Nilsson, 2002; Zamolodchikov et al., 2013; Pyzhev and Vaganov, 2019), a lot of studies are focused on analyzing productive forest function under changing climatic conditions, which may increase or decrease growing stocks and, as a result, their commercial potential (Boisvenue and Running, 2006; Liang et al., 2016; Mendelsohn et al., 2016). Positive dynamics in forest productivity may entail more wood harvests and timber supply on global timber markets (Garcia-Gonzalo et al., 2007). Annual global demand dynamics for firewood and biofuel is expected to be positive as well (Kirilenko and Sedjo, 2007; Tian et al., 2016).

Apart from positive impacts, there is a set of climate-induced factors that drive forest degradation and are commonly referred to as natural disturbances. For instance, detrimental windstorms along with shortening soil frost duration may result in windthrow spreading (Saad et al., 2017). Droughts arising from permanent temperature rise with low humidity are usually accompanied with insect infestations (Volney and Fleming, 2000) and frequent wildfires (Flannigan et al., 2000; Shvidenko and Schepaschenko, 2013) that are key stressors undermining sustainability of forest ecosystems and dark needle coniferous tree species in particular (Kharuk et al., 2017). All these kinds of natural disturbances adversely influence logging industry through shrinkage of forest resources available for harvesting. Additionally, economic analysis of these harmful impacts in terms of damage costs accounting still meets many difficulties (Ivantsova et al., 2019).

In the response to climate change the most vulnerable tree species adapt by migration towards more suitable environmental conditions mostly to high-latitude northern areas. In the eastern United States over the past 30 years there was a considerable westward and northward shift of tree habitats that occurred due to the changes in moisture regimes of ecosystems (Fei et al., 2017). In central Siberia the northern forests edge moved a lot further upwards than southern one and changes in species distribution in favor of birch and spruce species domination were identified (Tchebakova et al., 2011). According to some findings, an increase in air temperature in the long run will propel shift of the most vulnerable to drought coniferous towards tundra with milder climate, so in the south stands are expected to be replaced with

expanding steppes, resulting in 8-10% diminution in the total area of light and dark-coniferous by 2080 (Tchebakova et al., 2016). As a result, logging activities will move mainly northward following the trajectory of forest migration (Kirilenko and Sedjo, 2007). In European forests under the scenario of infinite greenhouse gases emissions the range of cold-adapted Norway spruce is projected to shrink by over 60% and be supplanted by Mediterranean oak (Hanewinkel et al., 2013). Diverse forest tree species differently respond to environmental factors alteration, for this reason with warmer and more arid conditions drought-resistant broadleaves are likely to displace more commercially valuable but less resilient coniferous (Drobyshev et al., 2013; Johnstone et al., 2010).

Although logging industry experience indirect consequences of global warming processes, there is a set of direct effects detrimental to forest sector. Extreme weather events in forms of windstorms, hail and heavy rains make performance of harvesting operations dangerous for loggers (Rittenhouse and Rissman, 2015). There is also a risk of getting lost logs while floating down the river due to increased frequency of windstorms and spring floods (Hellmann et al., 2015). Finally, an additional direct impact of climate change on forest industry is a gradual shortening of winter logging season under the rising air temperatures which might result in lesser wood harvested annually (Goltsev and Lopatin, 2013; Chugunkova and Pyzhev, 2020).

In fact, there are few studies on economic consequences of climate change in Russian forestry. For example, Pyzhev (2020) analyzed cause-and-effect relationship between main climatic characteristics of temperature and precipitation and logging volumes for the regions of Siberia and the Far East. In turn, Goltsev and Lopatin (2013) forecasted a reduction in duration of winter-felling season for Tihvin district in Leningrad Oblast.

The same results of shortening winter logging season under the rising air temperatures were obtained for Krasnoyarsk Krai and Irkutsk Oblast in the research by Chugunkova and Pyzhev (2020). The presented study shares the database from (ibid) to reveal the dependence of harvested wood volumes on logging season duration on the territory of Siberian regions from 1966 to 2018.

Data and Methods

In Siberia as well as in some other Russian regions logging companies perform harvest activities during the period, when forest ground freeze enough to enable heavy logging machinery to access forest sites. This period usually spans entirely winter and partially autumn and spring months, so it can be reasonably identified as winter logging season.

Two Siberian regions, Krasnoyarsk Krai and Irkutsk Oblast, were selected as sampling areas for my research due to the fact these regions take leading positions representing the highest share in the total timber volume harvested nationally (Gordeev and Pyzhev, 2015). In 2018, Irkutsk Oblast and Krasnoyarsk Krai accounted for 15 % (35.7 million m^3) and 12 % (28.6 million m^3) of total wood harvested in Russia respectively (UIISS, 2020), thus could be reasonably referred to as the two largest logging territories of Russia.

Two key indicators are in the focus of the analysis: duration of winter logging season and logging volumes.

To estimate the expectable duration of logging season, sets of temperature observations from meteorological stations that are located near felling sites of Krasnoyarsk Krai and in Irkutsk Oblast were used. These stations are Yeniseysk, Boguchany, Achinsk, Minusinsk in Krasnoyarsk Krai and Bratsk, Kirensk, Tulun, Yerbogachen in Irkutsk Oblast. The data were derived from the State Data Holding via Web technology AISORI provided by the All-Russia Research Institute of Hydrometeorological Information – World Data Center (Bulygina et al., 2019). The temperature observations were used to estimate winter logging season duration by each station for the period of 1966-2018 in accordance with the methodology by Chugunkova and Pyzhev (2020).

Data on logging volumes for Krasnoyarsk Krai and Irkutsk Oblast were collated from The Federal Forestry Service's statistical reference book entitled "Forest Management in Russian Federation in 1946-1992 years" (RICFR, 1996).

Until 1991, Krasnoyarsk Krai covered the territory of the present Khakassia, hence the period of 1966-1991 reflects logging volumes for the expanded territory of Krasnoyarsk Krai. The further information on harvesting operations in 1995, 1998, 2000, 2002, 2004-2006 and 2009-2018 years was gained from another reference book "Forest complex of Russian Federation and foreign countries" (MSFU, 2008) and UI-ISS database respectively (UIISS, 2019). To recover missing information on harvested wood volumes, a linear interpolation method was applied. The data were restored based on adjacent given values with a trivial linear equation: $Y = a_0 + a_1 L$, where Y is a calendar year and L is a logging volume in the related year.

To identify the dependence of harvested wood volumes on logging season duration on the territory of Siberian regions from 1966 to 2018, autoregressive distributed lag modeling framework was used. In this model the dependent variable is regressed on its own lagged values and lagged values of an independent variable. ARDL model of (p,q) consists of p lags of independent and q lags of dependent series and is given as:

$$L = a_0 + b_1 S_{t-1} + b_2 S_{t-2} + \ldots + b_p S_{t-p} + a_1 L_{t-1} + a_2 L_{t-2} + \ldots + a_2 L_{t-q} + e_t, \qquad (1)$$

where a_0 is a constant, b_1, b_2, … b_p and a_1, a_2, … a_p – model parameters and e_t – error term (Demirhan, 2020), L is a logging volume in Krasnoyarsk Krai or Irkutsk Oblast and S is a winter logging season duration on meteorological station located within the respective region.

Results and conclusion

Prior to modeling, time series were tested for unit root presence. Both ADF and KPSS unit root tests were used for the modeling purposes, since they provide a bit different approaches to check a stationary process presence. If the null hypothesis is not rejected in ADF (i.e. non-stationarity) or rejected in KPSS (i.e. stationarity) a first-order difference is taken to make a time series stationary, then it is tested again and differenced until the process is stationary. When getting mixed and inconsistent test results, KPSS test seems to be more preferable as it provides more robust results (Table 1).

Next, four ARDL models were evaluated for each region. I used lowest AICc criteria to find out a total number of lag orders for each model and got from 6 to 12 of them for both Krasnoyarsk Krai and Irkutsk Oblast (Tables 2 and 3). Most notably, there were significant coefficients within a distributed lag term in all models, so this lead me to infer that there is a relationship between logging volumes and winter logging season across all considered meteorological stations.

In fact, permanently increasing air temperatures under the global climate change might result in shortening duration of winter

Table 1. The order of differencing (I) in time series data based on ADF and KPSS unit root tests

Indicator	I	
	ADF	KPSS
Logging volumes (Krasnoyarsk Krai)	2	2
Logging volumes (Irkutsk Oblast)	2	1
Logging season duration (Yeniseysk)	0	1
Logging season duration (Boguchany)	0	1
Logging season duration (Achinsk)	0	1
Logging season duration (Minusinsk)	0	1
Logging season duration (Bratsk)	0	1
Logging season duration (Kirensk)	0	1
Logging season duration (Tulun)	0	1
Logging season duration (Yerbogachen)	0	0

Source: elaborated by author.

Table 2. Results from ARDL modeling by the meteorological stations of Krasnoyarsk Krai, 1966-2018

	Yeniseysk	Boguchany	Achinsk	Minusinsk
const	199.986 (181.462)	77.378 (237.54)	129.123 (166.904)	125.804 (160.683)
a_1	−0.553***[1] (0.183)	−0.472** (0.189)	−0.62*** (0.141)	−0.567*** (0.14)
a_2	0.1 (0.201)	0.037 (0.199736)	0.227 (0.176)	0.102 (0.146)
a_3	0.52** (0.199)	0.455* (0.213)	0.6333** (0.243)	0.578** (0.23)
a_4	0.013 (0.19)	0.113 (0.255)	0.042 (0.214)	0.107 (0.141)
a_5	−0.499** (0.2)	−0.255 (0.237)	−0.614** (0.242)	−0.577*** (0.204)
a_6	−0.327** (0.146)	0.172 (0.175)	−0.472** (0.182)	−0.544*** (0.185)
a_7		0.533** (0.245)		
a_8		−0.013 (0.217)		
a_9		−0.139 (0.217)		
a_{10}		−0.252 (0.197)		
a_{11}		0.279 (0.165)		
a_{12}		0.141 (0.218)		
b_1	23.1* (12.287)	−4.689 (17.108)	9.776 (11.384)	−4.226 (11.052)
b_2	24.277 (16.729)	2.237 (14.154)	14.69 (17.085)	13.435 (18.058)
b_3	27.308 (19.678)	−4.292 (18.899)	−12.141 (18.574)	−13.887 (17.746)
b_4	1.787 (18.386)	−27.418 (18.006)	−35.56* (17.73)	−43.766** (19.42)
b_5	18.035 (16.091)	−24.039 (22.348)	−12.276 (17.557)	−29.07* (16.395)
b_6	5.196 (13.144)	−32.171 (24.096)	1.122 (13.125)	−16.654* (9.323)
b_7		−48.251** (22.29)		
b_8		−57.885* (28.513)		
b_9		−67.421*** (20.059)		
b_{10}		−53.15** (19.803)		
b_{11}		−35.406** (14.966)		
b_{12}		−43.593* (21.428)		
R^2	0.521	0.762	0.624	0.653

Source: elaborated by author.

[1] The symbols ***, **, * hereinafter denotes significance at 1 %, 5 % and 10 % levels correspondingly.

Table 3. Results from ARDL modeling by the meteorological stations of Irkutsk Oblast, 1966-2018

	Bratsk	Kirensk	Tulun	Yerbogachen
const	73.876 (207.831)	256.941 (211.43)	154.642 (189.235)	−9905.47* (5347.49)
a_1	0.649*** (0.201345)	0.646*** (0.19)	0.528*** (0.172)	0.455*** (0.129)
a_2	0.063 (0.195)	0.056 (0.271)	0.089 (0.184)	0.271* (0.152)
a_3	−0.219 (0.207)	0.005 (0.214)	−0.24 (0.225)	0.19 (0.145)
a_4	0.387* (0.215)	0.521** (0.225)	0.572** (0.219)	0.095 (0.177)
a_5	0.08 (0.164)	0.161 (0.3)	0.116 (0.14)	0.081 (0.164)
a_6	−0.671*** (0.15)	−0.777*** (0.245)	−0.656*** (0.14)	−0.438*** (0.117)
a_7	0.371* (0.203)	0.006 (0.189)	0.117 (0.193)	
a_8	−0.056 (0.198)	0.104 (0.261)	0.157 (0.176)	
a_9		−0.271 (0.22)		
a_{10}		0.284 (0.276)		
a_{11}		0.182 (0.258)		
b_1	1.749 (14.18)	10.4189 (11.788)	−3.861 (13.613)	−2.098 (12.577)
b_2	25.901 (19.836)	34.619** (14.589)	22.234 (15.204)	11.495 (10.21)
b_3	59.696** (21.954)	95.174*** (22.434)	80.715*** (20.463)	44.259*** (9.114)
b_4	45.195* (23.561)	93.081*** (28.897)	75.733*** (19.329)	16.566 (13.413)
b_5	59.904** (23.355)	98.895*** (25.025)	73.122*** (20.559)	13.437 (12.864)
b_6	58.83*** (18.997)	49.239* (26.361)	54.826** (22.277)	−28.268* (15.125)
b_7	46.205*** (16.297)	43.577* (22.906)	65.822*** (20.155)	
b_8	41.28*** (12.215)	21.757 (22.616)	48.416*** (16.21)	
b_9		20.099 (20.315)		
b_{10}		37.356* (18.589)		
b_{11}		26.074* (14.169)		
R^2	0.763	0.873	0.793	0.773

Source: elaborated by author.

logging season on the territory of Siberian regions (Chugunkova and Pyzhev, 2020). As a consequence, this means less wood harvests per season, so logging industry could become unprofitable in the long run. To reduce such a negative impact, mitigation and, that is more important, adaptation activities in forestry are sorely needed.

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Моделирование динамики развития лесозаготовительной промышленности под влиянием глобального изменения климата: пример регионов Сибири

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Аннотация. Лесное хозяйство как одна из отраслей эконо́мки испытывает на себе влияние множества факторов, и глобальное изменение климата является одним из них. Климатические изменения могут влиять на лесную отрасль как напрямую, так и косвенно через изменение количественных и качественных характеристик леса, а также позитивным либо негативным образом. Изучение основных экономических последствий глобального изменения климата для лесного хозяйства России требует к себе более детального внимания со стороны академического сообщества и органов власти. Одним из таких последствий является сокращение длительности зимнего лесозаготовительного сезона, что может привести к уменьшению объемов заготовки древесины в долгосрочной перспективе. На основе данных об объемах заготовки древесины в Красноярском крае и Иркутской области, а также длительности зимнего сезона по метеостанциям указанных регионов за период 1966–2018 гг. было построено восемь моделей ARDL, которые показали наличие зависимости объемов заготовки древесины от длительности лесозаготовительного сезона по всем рассмотренным метеостанциям. Для того чтобы минимизировать негативное влияние потепления на лесную отрасль в виде предстоящего сокращения объемов заготавливаемой древесины, необходима реализация комплекса мер по адаптации отрасли к изменяющемуся климату.

Научная специальность: 08.00.05 — экономика и управление народным хозяйством.