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Incidence of Russian log export tax: A vertical log-lumber model

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ABSTRACT

In 2007, Russia imposed an ad valorem tax on its log exports that lasted until 2012. In this paper, we use a Muth-type equilibrium displacement model to investigate the market and welfare impacts of this tax, utilizing a vertical linkage between log and lumber markets and considering factor substitution. Our theoretical analysis indicates that, without considering the vertical linkage, the negative effects of log export tax on equilibrium price for log producers is underestimated when logs and processing services are gross substitutes, and the direction of bias is uncertain when they are gross complements. Empirical simulations show that the burden of Russian log export tax is shared almost equally between foreign log buyers and domestic log producers and that the tax increases domestic lumber production. Further, the marginal effect of the log export tax on domestic lumber production decreases as Russian domestic demand share of logs increases. Overall, the welfare gains for Russian lumber consumers, lumber producers in the form of quasi-rents to processing services, and tax revenue exceed the loss in its logging sector.

Introduction

Russia is one of the world's largest exporters of coniferous logs. In 2006, its log exports reached 36.4 million m^3, which was more than six times in 1992 and contributed to 44.5% of the world's total softwood log exports (Food and Agriculture Organization of the United Nations or FAO, 2017). However, the vast forest resources in Russia have not contributed significantly to the country's economic growth because of lack of investments and low level of resource utilization in its forest sector (Torniainen et al., 2006). To stimulate domestic lumber production, Russia imposed an ad valorem export tax of 6.5% on January 1, 2007, rising to 20% on July 1, 2007 and 25% on April 1, 2008 (van Kooten and Johnston, 2014). Russia originally intended to introduce another round of tax increase from 2009, but postponed the move following protests from neighboring countries and sharply dropped international demands on wood products after the 2008 financial crisis. When Russia joined the World Trade Organization (WTO) on August 22, 2012, it was forced to reduce the export tax on softwood logs to between 13 to 15% within a quota while the rate remains at 25% beyond the quota (WTO, 2017). As the quota volume was set below previous trade levels, log export volumes in 2013 was 4% lower as compared to 2012. As a result of all these restrictions and falling international demands, Russian softwood log exports declined drastically to 12.7 million m^3, or 15.5% of total global trade, in 2016 (FAO, 2017).

The purpose of this study is to estimate the incidence of the Russian log export tax between 2007 and July 2012 and to assess its effectiveness. Even though Russia has changed its log export restrictions to a tariff-rate quota system since August 22, 2012, this analysis is relevant and has policy implications because it provides a basis for comparing different systems in Russia. Furthermore, it can inform public policy if a similar tax is implemented in other jurisdictions. From an academic and analytical perspective, it fill the void in literature on this particular tax in Russia, which presents a unique opportunity to assess the extent to which a vertical market linkage might affect tax incidence. Conventional theory indicates that export taxes on raw materials (e.g., logs) can reduce domestic log price which in turn boosts domestic production and exports of finished goods (e.g., lumber). However, ignoring the interdependence between log and lumber markets in a global supply chain and possible factor substitution may produce biased estimations on the price, production, and welfare effects of the log export tax.

Simeone (2012) uses descriptive statistical analysis to look into Russian market share change in international log markets before and after the implementation of log export tax. The other two

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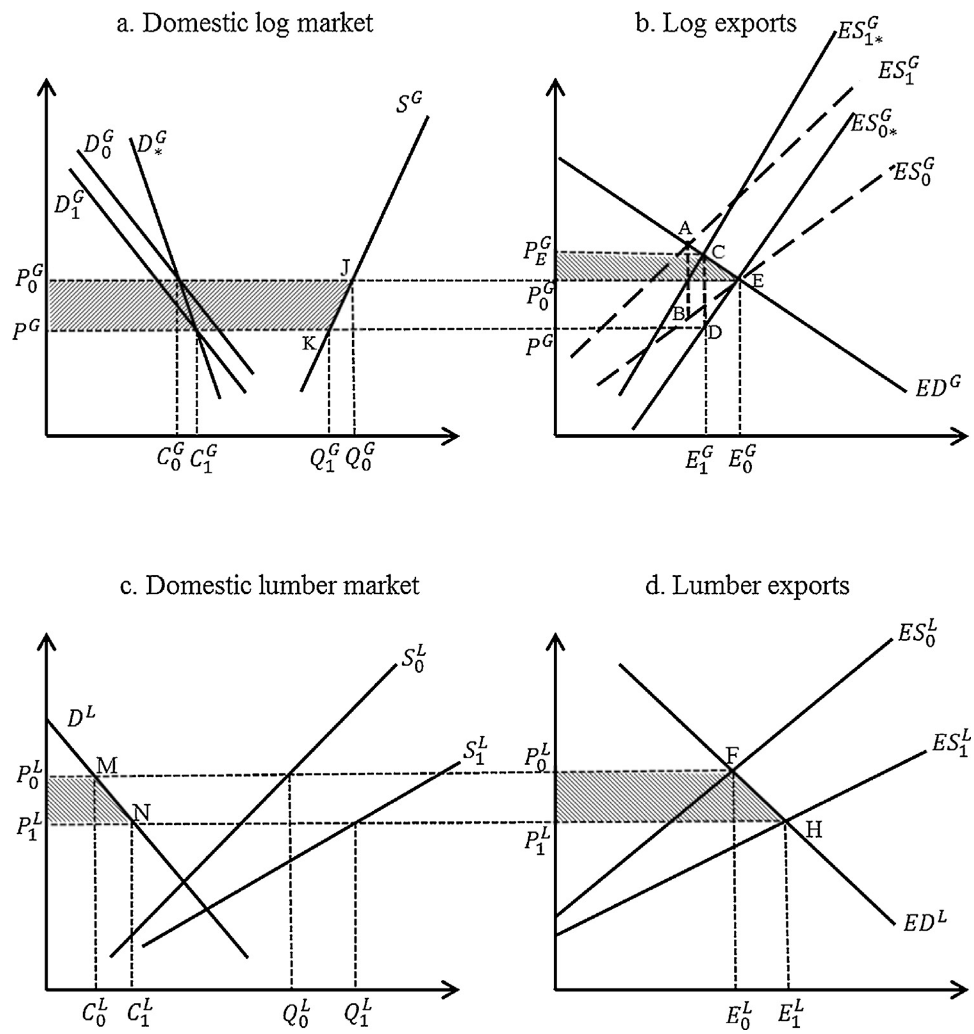

Fig. 1. The effects of Russian log export tax: Vertical log-lumber markets.

Source: Authors' analyses.

studies, Solberg et al. (2010) and van Kooten and Johnston (2014) include multiple wood products in their analyses. Using a global forest sector model (EFI-GTM), Solberg et al. (2010) predict the price and production of Russian and global forest products towards 2020 under alternative tax levels. However, the incidence of log export tax is still not transparent. van Kooten and Johnston (2014) estimate the market effects of Russian log export tax by developing an integrated log-lumber trade model from a global perspective and using simulations. Their main conclusion is that lifting the log export tax increases Russian welfare, which means that the tax has caused welfare loss to Russia. This conclusion, however, is contrary to the theory of optimal tax for a country with sufficient monopoly power in the world market (e.g., Sedjo and Lyon, 1992). Studies on log export restrictions in other jurisdictions include Zhang (1995), Johnson et al. (1995), and van Kooten (2014).

In this study, we use a Muth-type equilibrium displacement model (EDM) to measure the incidence of Russian log export tax based on a vertical log-lumber market linkage. The Muth-type EDM uses a less restrictive assumption that allows the possibility of substitution between factors of production (Alston, 1991). Moreover, it makes transparent the economic forces that determine tax incidence. Specifically, we estimate the impacts on price and quantity changes and the resulted benefits or costs to (1) Russian log producers, (2) Russian lumber producers (the consumers of Russian logs), (3) Russian treasury, (4) foreign log buyers, and (5) foreign lumber buyers. The sum of (1) to (3) is the net benefits or costs to Russia, and that of (4) to (5) is the net benefits or costs to the rest-of-the-world (ROW). The sum of Russian and ROW benefits and costs gives the total world benefits or deadweight loss.

This study differs from other investigations of this question insofar as it is based on a Muth-type EDM, considering factor substitution in lumber production and feedback effects on log demand. Furthermore, we illustrate the log-lumber market interaction in a graphical analysis. Finally, the primary parameters used in this study—the elasticities of supply and demand for Russian lumber and log—are directly estimated using recent data. Our main conclusion is that the export tax was beneficial to Russia and the average tax rate between 2007 and 2012 was suboptimal from Russia's perspective. The next section presents a graphical analysis of the impacts of Russian log export tax on domestic and overseas log and lumber markets, followed by a theoretical analysis. Sections parameter estimation and model calibration and simulation provide our elasticity estimates of Russian domestic and export markets for logs and lumber and estimates of the prices, quantities, and welfare effects associated with the tax. The final section concludes.

Graphical analysis

Lumber production uses two factors: logs and processing services. One stage analysis focuses on log markets only, without considering lumber markets. A vertical log-lumber model differs from one stage analysis in that prices of lumber and processing inputs are endogenous and have feedback effects on log demand. Fig. 1 presents a simple depiction of how the log export tax works in a partial-equilibrium setting, i.e., assuming prices of all goods but logs, processing services, and lumber remain constant, in all four related markets: Russian domestic log market, log export market, domestic lumber market, and lumber export market. The superscripts G and L indicate the variables or demand and supply curves for logs and lumber, respectively. The subscripts 0 and 1 indicate variable values under market clearing conditions before and after the implementation of Russian log export tax, respectively. We abstract from the fact that the rate of log export tax changed several times after 2007, although we consider it in our empirical estimations.

The intersection of the log export supply (ES_0^G) and demand (ED^G) curves gives the free market equilibrium price P_0^G on the log market, and the corresponding free market equilibrium price of lumber is P_0^L. With these prices Russia produces Q_0^G and Q_0^L units of logs and lumber, respectively, and exports E_0^G and E_0^L units to the ROW market. Without considering lumber and processing services markets, the ad valorem tax results in the left-shifted and counterclock wisely rotated export supply curve of logs from ES_0^G to ES_1^G. For a tax rate of τ, the absolute vertical shifts in the excess supply curve is the distance between A and B, with $AB = \tau \cdot P_0^G$.

However, there are feedback effects on domestic demand curve for logs when prices of lumber and processing services are endogenous. A decrease in domestic log price shifts lumber supply to the right and reduces lumber price. A lower lumber price shifts domestic log demand curve to the left. A decrease in domestic log price also changes the economic substitution between factor inputs, which in turn has another feedback effect on domestic log demand. The sign of cross-price effect must be positive in a two-input case (Varian, 1992). Yet, the gross effect on domestic log demand curve has no determinate sign. By price transmission relation between input factor and final (manufactured) product, the price of processing services decreases when logs and processing services are gross substitutes and increases when they are gross complements. In the former case, the domestic demand curve for logs shifts to the left due to lower prices of lumber and processing services. In the latter case, the shift direction for log demand is uncertain since a lower lumber price shifts it to the left while a higher price of processing services shifts it to the right.

Here in the graphical analysis, we focus on the circumstance when the gross effect is to shift domestic log demand curve to the left to be consistent with our parameter estimation in Section parameter estimation and model calibration. Abstracting from the temporal ordering of the stages of production, domestic log demand curve shifts from D_0^G to D_1^G, making the observed or actual domestic log demand curve as D_*^G. As Russian log export supply equals the difference between Russian log supply and domestic log demand, the original export supply curve (without tax) ES_0^G becomes ES_{0*}^G when prices of lumber and processing services are endogenous. With this log export tax, Russian log export supply curve shifts to ES_{1*}^G, and the vertical distance between the original and new curves (CD) is equal to $\tau \cdot P_0^G$ as well. In the new equilibrium, the log prices received by domestic producers and foreign buyers are P^G and P_E^G, respectively. With lumber supply curve shifts to S_1^L, lumber price decreases from P_0^L to P_1^L, and lumber export increases from E_0^L to E_1^L.

Again, as shown in Fig. 1a, the "actual" domestic equilibrium demand curve for logs is D_*^G, which traces out the demand responses to price changes in the log market holding the prices of lumber and processing services endogenous and the gross effect shifting domestic log demand to the left. This demand curve is less elastic than the one in which only log market is considered. A less elastic domestic demand would result in a less elastic Russian log export supply from ES_0^G to ES_{0*}^G. Tax burden would fall more on the less elastic side, which means that Russian log producers bear more tax burden than under an exogenous lumber and processing services market setting of ES_0^G in Fig. 1b.

Under the ad valorem tax rate τ, the distance of vertical shift CD is identical to AB, even though the burden of tax varies. In other words, without considering the vertical marketing channel from logs to lumber and a left-shifted domestic log demand curve, one tends to overestimate the effect of log export tax on increasing log price paid by foreign buyers and underestimate its effect on decreasing log price received by domestic producers and the resulted increases in lumber production and exports.

Model

Structural model

Muth (1964) develops a partial equilibrium model of firms' identical production using two factor inputs to measure the effects of retail demand and input supply shifts. It incorporates the interaction between vertical markets, which fits well with a log-lumber market analysis. Sun (2006) and Li and Zhang (1996) are among a few studies that use a two- (three-) processing-stage Muth-type EDM to estimate the welfare effects of forest policy. They are applications in a closed economy setting. We relax the assumption to an open economy setting and allow for trade in one of the inputs (logs) and output (lumber). This is important because Russia is a net exporter of both logs and lumber. As market distortions brought by an export tax on logs extend to both processing services and lumber markets, we consider two products and three markets in this study.

Following the basic assumption of a Muth-type EDM, in a vertical log-lumber model, lumber producers use two input factors (logs and processing services) under constant returns to scale (CRS). The export demand for Russian logs and lumber are assumed to be separate. By imposing a log export tax, Russian government gains tax revenue and domestic lumber producers receive an indirect subsidy from the resulted lower domestic log price.

With the above settings, our vertical log-lumber model for Russia is represented by (*a*) the lumber market in Eqs. (1)–(4), (b) the log market in Eqs. (5)–(9), and (c) demand and supply for processing services in Eqs. (10) and (11). In particular, Eq. (5) shows the vertical linkage between logs and lumber, and Eqs. (2) and (6) represent Russia's exports of lumber and logs, respectively. The log export tax is the wedge between domestic log price and export price, as shown in Eq. (7). This is our basic model for estimating the changes in prices and quantities of logs and lumber in both domestic and export markets that result from exogenous demand shifts caused by the log export tax.

$$D^L = \mathrm{D}\left(P^L\right) \quad \text{(Domestic demand for lumber)} \tag{1}$$

$$D_E^L = D_E\left(P^L\right) \quad \text{(Export demand for lumber from Russia)} \tag{2}$$

$$S^L = f\left(D^G, I\right) \quad \text{(CRS production function of lumber)} \tag{3}$$

$$S^L = D^L + D_E^L \quad \text{(Lumber market clearing)} \tag{4}$$

$$P^G = P^L \cdot f_{D^G}\left(D^G, I\right) \quad \text{(Inverse demand for logs in Russia)} \tag{5}$$

$$D_E^G = D^{\cdot}_E\left(P_E^G\right) \quad \text{(Export demand for logs from Russia)} \tag{6}$$

$$P_E^G = P^G(1+\tau) \quad \text{(Log export tax)} \tag{7}$$

$$S^G = S^G\left(P^G\right) \quad \text{(Supply for log)} \tag{8}$$

$$S^G = D^G + D_E^G \quad \text{(Log market clearing)} \tag{9}$$

$$P^I = P^L \cdot f_I\left(D^G, I\right) \quad \text{(Inverse demand for processing services)} \quad (10)$$

$$I = S^I\left(P^I\right) \quad \text{(Supply for processing services)} \quad (11)$$

where $f_i\left(i = D^G, I\right)$ in Eqs. (5) and (10) are the marginal physical products of logs and processing services, respectively (or the input demand functions for logs and processing services, respectively) holding output price constant.

This model contains one exogenous variable—the log export tax τ—and 11 endogenous variables. The endogenous variables are D^L (Russian demand for lumber), D^L_E (ROW demand for Russian lumber), S^L (Russian lumber supply), P^L (price of lumber), D^G (Russian demand for logs), D^G_E (ROW demand for Russian logs), S^G (Russian log supply), P^G (Russian domestic log price), P^G_E (export supply price of Russian logs), I (processing services in lumber production), and P^I (price of processing services in Russia).

We estimate the changes in endogenous prices and quantities by totally differentiating the equations above and converting them into elasticity forms:

$$\tilde{D}^L = \eta^L_R \tilde{P}^L \quad (1')$$

$$\tilde{D}^L_E = \eta^L_E \tilde{P}^L \quad (2')$$

$$\tilde{S}^L = k_G \tilde{D}^G + (1 - k_G)\tilde{I} \quad (3')$$

$$\tilde{S}^L = k_1 \tilde{D}^L + (1 - k_1)\tilde{D}^L_E \quad (4')$$

$$\tilde{P}^G = \tilde{P}^L - \frac{1 - k_G}{\sigma}\left(\tilde{D}^G - \tilde{I}\right) \quad (5')$$

$$\tilde{D}^G_E = \eta^G_E \tilde{P}^G_E \quad (6')$$

$$\tilde{P}^G_E = \tilde{P}^G + \tau \quad (7')$$

$$\tilde{S}^G = \varepsilon^G \tilde{P}^G \quad (8')$$

$$\tilde{S}^G = k_2 \tilde{D}^G + (1 - k_2)\tilde{D}^G_E \quad (9')$$

$$\tilde{P}^I = \tilde{P}^L + \frac{k_G}{\sigma}\left(\tilde{D}^G - \tilde{I}\right) \quad (10')$$

$$\tilde{I} = \varepsilon^I \tilde{P}^I \quad (11')$$

Eqs. (1′)–(11′) are expressed in percentage changes.[1] $\eta^L_R(<0)$ and $\eta^L_E(<0)$ are the own-price elasticities of demand for lumber of Russia and the ROW. $\sigma(\geq 0)$ is the elasticity of substitution between the two input factors—logs and processing services. $\eta^G_E(<0)$ is the own-price elasticity of demand for log of the ROW. $k_1 = D^L/S^L$ and $k_2 = D^G/S^G$ are domestic demand shares of lumber and logs, respectively. $k_G = P^G D^G / P^L S^L$ is the input share of logs in lumber production. $\varepsilon^G(>0)$ and $\varepsilon^I(>0)$ are the own-price elasticities of supply for logs and processing services. The tax shift is in price direction. For example, $\tau = 0.01$ represents a one percent shift of export supply of Russian logs to the left. The endogenous changes in quantities and prices are functions of exogenous tax shifts and parameters. Here we focus on deriving the reduced form for log price changes induced by the export tax. For comparison purpose, we first treat the prices of lumber and processing services as exogenous, even though we focus on the case in which they are endogenous in our empirical study.

Reduced form for log prices under exogenous prices of lumber and processing services

When the prices of lumber and processing services are exogenous, the effect of a log export tax on log export price is derived from Eqs. (5′)–(9′) only. In other words, we drop Eqs. (1′)–(4′), (10′), and (11′), and treat $\tilde{P}^L$ and $\tilde{P}^I$ $(\tilde{I})$ at constant level $\bar{P}^L$ and $\bar{P}^I$ $(\bar{I})$, respectively. Solve Eqs. (5′), (8′), and (9′) simultaneously for the export supply equation for logs to yield

$$\tilde{D}^G_E = \varepsilon^G_{exo} \tilde{P}^G - k\sigma \bar{P}^L - k\bar{I} \quad (12)$$

where $\varepsilon^G_{exo} = \frac{(1-k_G)\varepsilon^G + k_2\sigma}{(1-k_G)(1-k_2)} > 0$ is the export supply elasticity for logs and $k = \frac{k_2}{(1-k_G)(1-k_2)} > 0$. Deleting the last two terms and setting Eq. (12) equal to (6′) and using Eq. (7′), we have the quasi reduced-form equations of domestic and export prices of logs with respect to the export tax

$$\frac{\tilde{P}^G_E}{\tau} = \frac{\varepsilon^G_{exo}}{\varepsilon^G_{exo} - \eta^G_E} \quad (13)$$

$$\frac{\tilde{P}^G}{\tau} = \frac{\eta^G_E}{\varepsilon^G_{exo} - \eta^G_E} \quad (14)$$

Since $\varepsilon^G_{exo} > 0$ and $\eta^G_E < 0$, the tax is split between a rise in the export price and a fall in the domestic price for logs ($\frac{\tilde{P}^G_E}{\tau} + |\frac{\tilde{P}^G}{\tau}| = 1$). In general, foreign consumers bear less of the tax incidence (a lower value of $\frac{\tilde{P}^G_E}{\tau}$) and domestic producers bear more (a higher value of $|\frac{\tilde{P}^G}{\tau}|$) when export supply becomes less elastic (a smaller ε^G_{exo}) in relation to export demand.

Reduced form for log prices under endogenous prices of lumber and processing services

Keeping P^L as temporarily exogenous and solving Eqs. (1′), (3′), and (4′) simultaneously yield the export supply curve for lumber as

$$\tilde{D}^L_E = \varepsilon^L_e \tilde{P}^L + \frac{k_G}{1 - k_1}\tilde{D}^G + \frac{1 - k_G}{1 - k_1}\tilde{I} \quad (15)$$

where $\varepsilon^L_e = -\frac{k_1 \eta^L_R}{1-k_1} > 0$ is the export supply elasticity of lumber. Substituting Eqs. (2′), (10′), and (11′) into Eq. (15), we get the price transmission relation between processing services and lumber

$$\tilde{P}^I = \frac{\eta^L + \sigma}{\varepsilon^I + \sigma}\tilde{P}^L \quad (16)$$

where $\eta^L = k_1 \eta^L_R + (1 - k_1)\eta^L_E$ is the overall demand elasticity for lumber.

Substitute $\tilde{D}^G - \tilde{I} = \frac{\sigma}{k_G}\left(\tilde{P}^I - \tilde{P}^L\right)$ from Eq. (10′) into (5′), we have

$$\tilde{P}^L = k_G \tilde{P}^G + (1 - k_G)\tilde{P}^I \quad (17)$$

Combining Eqs. (11′), (12), (16), and (17), we get the reduced-form export supply equation for logs allowing the prices of lumber and processing services to adjust

$$\tilde{D}^G_E = \varepsilon^G_{exo}\tilde{P}^G - k\delta\left(\sigma + \varepsilon^I \frac{\eta^L + \sigma}{\varepsilon^I + \sigma}\right)\tilde{P}^G \quad (18)$$

where $k > 0$ as defined in Section reduced form for log prices under exogenous prices of lumber and processing services and $\delta = \frac{k_G(\varepsilon^I + \sigma)}{(k_G - 1)\eta^L + k_G\sigma + \varepsilon^I} > 0$. Eq. (18) indicates that the export supply elasticity for logs when the prices of lumber and processing services are endogenous is

$$\varepsilon^G_{end} = \varepsilon^G_{exo} + \Phi \quad (19)$$

[1] For derivations of the basic equations, refer to Muth (1964) and Wohlgenant (1989).

where $\Phi = -k\delta\left(\sigma + \varepsilon^I \frac{\eta^L+\sigma}{\varepsilon^I+\sigma}\right)$. The reduced-form equations of log prices with respect to the tax when prices of lumber and processing services are endogenous are

$$\frac{\tilde{P}_E^{G'}}{\tau} = \frac{\varepsilon_{end}^G}{\varepsilon_{end}^G - \eta_E^G} = \frac{\varepsilon_{exo}^G + \Phi}{\varepsilon_{exo}^G - \eta_E^G + \Phi} \quad (13')$$

$$\frac{\tilde{P}^{G'}}{\tau} = \frac{\eta_E^G}{\varepsilon_{end}^G - \eta_E^G} = \frac{\eta_E^G}{\varepsilon_{exo}^G - \eta_E^G + \Phi} \quad (14')$$

Since the sign of term Φ is uncertain, the export supply curve may be more or less elastic compared to the one market analysis of logs. When $|\eta^L| < \sigma$, logs and processing services are gross substitutes,[2] and $\varepsilon_{end}^G < \varepsilon_{exo}^G$ ($\Phi < 0$) indicates that export supply becomes less elastic when we consider the vertical link between logs and lumber markets. In this case, Russian log producers bear more of the tax burden. In other words, the negative effects of log export tax on the equilibrium price for log producers will be underestimated if we only consider the log market, which is to say that the absolute value of $\frac{\tilde{P}^{G'}}{\tau}$ in Eq. (14′) is greater than that of $\frac{\tilde{P}^G}{\tau}$ in Eq. (14). However, when $|\eta^L| > \sigma$, logs and processing services are gross complements. In this case, we can only have $\varepsilon_{end}^G < \varepsilon_{exo}^G$ if $\sigma\left(\varepsilon^I + \sigma\right) > -\varepsilon^I\left(\eta^L + \sigma\right)$.

Welfare calculations

Numerical solutions can be obtained by substituting the values of tax and parameters into Eqs. (1′) through (11′) and then solving for the percentage changes in prices and quantities. To measure welfare impacts, we assume that the supply and demand curves are linear in their relevant ranges. This linear assumption provides a good approximation regardless of the true functional forms of supply and demand curves (Alston et al., 1995). As Alston (1991) and Lusk and Anderson (2004) show, once the changes in equilibrium prices and quantities are obtained, the welfare distributions are measured as

$$\Delta CS^L = -P_0^L D_0^L \tilde{P}^L\left(1 + 0.5\tilde{D}^L\right) \quad (20)$$

$$\Delta PS^G = P_0^G S_0^G \tilde{P}^G\left(1 + 0.5\tilde{S}^G\right) \quad (21)$$

$$\Delta PS^I = P_0^I I_0 \tilde{P}^I\left(1 + 0.5\tilde{I}\right) \quad (22)$$

$$TR = P_{E0}^G D_{E0}^G \cdot \tau\left(1 + \tilde{D}_E^G\right) \quad (23)$$

$$\Delta CS_E^G = -P_{E0}^G D_{E0}^G \tilde{P}_E^G\left(1 + 0.5\tilde{D}_E^G\right) \quad (24)$$

$$\Delta CS_E^L = -P_0^L D_{E0}^L \tilde{P}^L\left(1 + 0.5\tilde{D}_E^L\right) \quad (25)$$

where ΔCS^L is the welfare change for Russian lumber consumers as indicated by area $P_0^L P_1^L NM$ in Fig. 1c, ΔPS^G is the welfare change for Russian log producers as measured in quasi-rents to logs of area $P_0^G P^G KJ$ in Fig. 1a, and ΔPS^I is the welfare change for Russian lumber producers as measured in quasi-rents to processing services.[3] Russian government receives tax revenue TR as indicated by area $P_E^G P^G DC$ in Fig. 1b. The sum of Eqs. (20)–(23) is the total welfare change to Russia. The welfare changes to foreign log and lumber buyers are ΔCS_E^G and ΔCS_E^L as indicated by areas $P_E^G P_0^G EC$ and $P_0^L P_1^L HF$ in Fig. 1b and d, respectively. The variables with subscript 0 take their values at the initial market equilibrium in the base year.

Parameter estimation and model calibration

Usually, the values of parameters in Eqs. (1′)–(11′) are taken from literature. As far as we know, there is no study measuring the demand and supply elasticities of Russian log and lumber.[4] Solberg et al. (2010) assume the price elasticity of log supply to be 1.5 in Russia and the price elasticity for end forest product demand to be −0.2 to −0.3 and use a global forest sector model to predict Russian and global forest product markets under different tax levels. This elasticity of log supply is much higher than that of the other regions measured in literature (e.g., Newman, 1987; Newman and Wear, 1993; Niquidet and Tang, 2013).

In this study, we estimate the elasticities using time series models of the domestic and export markets for Russian logs and lumber. The demand or supply quantity Q_t is a function of price P_t and a vector of lagged quantity Q_{t-i}, which is specified as

$$\ln Q_t = \alpha + \beta \cdot \ln P_t + \vartheta \cdot \ln Q_{t-i} + \varepsilon_t \quad (26)$$

To estimate the prices and quantities impacts through Eqs. (1′)–(11′) and welfare effects through Eqs. (20)–(25), we need to estimate six parameters

η_R^L (Russian demand elasticity for lumber),

η_E^L (export demand elasticity for lumber from Russia),

η_E^G (export demand elasticity for logs from Russia),

ε^G(Russialogssupplyelasticity),

ε^I(processingservicessupplyelasticity), and

σ(substitutionelasticitybetweenlogsandprocessingservices).

These parameters are β in Eq. (26), which we estimate based on their corresponding quantity and price values. Since we introduce the lag $\ln Q_{t-i}$ of the dependent variable as an exogenous variable in the partial adjustments model in Eq. (26), $\ln Q_t$ and $\ln P_t$ should be first-difference stationary and the residual ε_t is white noise. The presence of serial correlation is an evidence of model misspecification, which may be corrected by including additional lags of the dependent variable (Pickup, 2014). However, there may be estimation biases of β from two sources. One is that price may be endogenous since we omitted control variables. The other problem is simultaneous equation bias. To control for these biases, we first instrument the price variable with its lag value and the other variables in Eqs. (1)–(11). Then the final instruments in 2SLS regression are selected following a general-to-specific methodology to avoid over-identification.

We collected data for the time period between 1992 and 2014. Data on Russian production, consumption, and exports in logs and lumber are from FAO (2017). Price is defined as the ratio of total value to total quantity as a common practice in trade studies (Shiells, 1991; Luo et al., 2015). The value of processing services is determined as the annual difference between the value of processed lumber and cost of logs. We use inflation-adjusted per capita GDP in Russia as the price of processing services and derive the quantity of processing services by dividing its value with the

[2] See Alston and Scobie (1983), Kinnucan et al. (2000), and Kinnucan and Zhang (2015).

[3] These equations measuring producer surplus changes are valid since there are no shifts in both factor supply curves. For the case of pivotal shifts in factor supply, see Chung and Kaiser (1999).

[4] The Global Forest Products Model uses demand elasticities of end products (like coniferous lumber) for major countries without considering product sources. It does not have demand elasticity for logs since logs are factor inputs. In our paper, coniferous logs are inputs as well as an intermediate product for exports. Therefore, we estimate domestic and export demand elasticities separately in following analysis.

Table 1
Parameters and baseline values for Russian lumber and logs sectors.

Item	Definition	Value	S.E.
η_R^L	Domestic demand elasticity for lumber	−0.21	0.09
η_E^L	Export demand elasticity for lumber from Russia	−0.32	0.12
η_E^G	Export demand elasticity for logs from Russia	−0.41	0.11
ε^G	Domestic logs supply elasticity	0.12	0.10
ε^I	Domestic processing services supply elasticity	0.40	0.10
σ	Factor substitution elasticity	0.21	0.02
k_G	Input share of logs in lumber production	0.65	0.07
k_1	Domestic demand share of lumber	0.34	0.03
k_2	Domestic demand share of logs	0.47	0.05
$P_0^L D_0^L$	Value of domestic lumber demand (2005 US $ billion)	1.18	na
$P_0^G S_0^G$	Value of supplied logs (2005 US $ billion)	4.75	na
$P_0^I I_0$	Value of processing services (2005 US $ billion)	1.20	na
D_{E0}^G	Export demand quantity for logs from Russia (million m^3)	36.40	na
P_{E0}^G	Export demand price for logs from Russia (2005 US $/m^3)	69.37	na
$P_0^L D_{E0}^L$	Value of export demand for lumber from Russia (2005 US $ billion)	2.25	na
$P_{E0}^G D_{E0}^G$	Value of export demand for logs from Russia (2005 US $ billion)	2.53	na

Note: Elasticity parameters are authors' estimations using FAO data from 1992 to 2014. Shares and values of demand and supply are from FAO (2017). Baseline values are in 2006, the year before the implementation of Russian log export tax.

price.[5] Pre-estimation tests and regressions in Tables 2 and 3 are programed in *Stata 13.0*. As shown in Table 2, all variables are first-difference stationary based on Augmented Dickey–Fuller and Phillips–Perron unit root tests (Phillips and Perron, 1988; Becketti, 2013).

The OLS and 2SLS estimation results of Eq. (26) are presented in Table 3. Durbin and Wu-Hausman tests cannot reject the exogeneity hypothesis for the potentially endogenous price variable at the 10% level for all estimations. Therefore, we confine our results to the OLS estimation. Residual correlation is checked by ARCH LM test and Durbin's H-test. The null hypothesis of no serial correlation cannot be rejected at the 5% significant level with one lag except for the estimation of processing services supply function ($\ln I$). We add a second lag of dependent variable $\ln I_{t-2}$ to control for possible serial correlation in this equation.

The foreign lumber buyers (elasticity = −0.32) are more responsive to lumber price compared to Russian domestic consumers (elasticity = −0.21). The excess demand elasticity for Russian logs is around −0.41. China is the largest importer both of Russian logs and lumber. Sun (2014) estimates the Marshallian demand elasticity of −0.41 for China's demand for coniferous roundwood from Russia, which is similar to the results of our study. Russian log supply is inelastic with an elasticity of 0.12, although it is insignificant at the 10% level.

Factor substitution elasticity is estimated based on Eq. (5′). The empirical model is

$$\ln(P_t^G/P_t^L) = a + \gamma \ln(D_t^G/I_t) + e_t \qquad (27)$$

The dependent and independent variables are all level stationary (Table 2). The estimated value for γ is −1.66 (S.E. = 0.42). The input share of logs in lumber production was 0.65 in 2006. With

[5] There is no estimate on the supply elasticity for processing services in literature. Here we use the per capita GDP as the price for processing services because labor cost is the second largest component of lumber manufacturing cost.

Table 2
Stationarity analysis of variables.

	ADF		PERRON	
	level	1st differenced	level	1st differenced
$\ln D^L$	−2.46	−5.49***	−2.48	−5.40***
$\ln P^L$	−2.38	−10.32***	−2.39	−8.93***
$\ln D_E^L$	0.04	−4.10***	−0.10	−4.17***
$\ln D_E^G$	−2.16	−6.07***	−2.14	−5.66***
$\ln P_E^G$	−0.87	−4.51***	−1.03	−4.47***
$\ln S^G$	−2.54	−15.04***	−2.53	−11.69***
$\ln P^G$	−1.65	−4.83***	−1.80	−4.73***
$\ln I$	−1.96	−7.78***	−1.87	−6.86***
$\ln P^I$	0.38	−2.72*	−0.08	−2.62
$\ln(P^G/P^L)$	−15.73***	na	−15.03***	na
$\ln(D^G/I)$	−4.96***	na	−4.87***	na

Source: Authors' estimations.

$-\frac{1-k_G}{\sigma} = \gamma$, we get an approximate value for factor substitution elasticity σ of 0.21. Stier (1980) estimates the elasticity of substitution in lumber processing of 0.27 in the United States, which is similar to what we get for Russia. These elasticity estimates and other parameters in Table 1 are used as the baseline values for our deterministic simulations.

Besides deterministic simulations, we present stochastic simulations on the marginal effects of a 1% ad valorem export tax on prices and quantities. In the stochastic simulations, the parameters in Table 1 are treated as random variables following a normal distribution. The standard errors of k_G, k_1, and k_2 are calculated assuming that the lower and upper bounds of their 95% confidences intervals are 0.8 and 1.2 times their respective baseline values. The real standard error of ε^G is assumed to be half of its estimated value. Mean values and confidence limits of marginal effects are computed using the software package *Simetar*, a spreadsheet add-in in *Excel*.

Simulation

Table 4 presents the results of our simulations. While the results from our deterministic simulations are strictly from the application of Eqs. (1′)–(11′), those of stochastic simulations are generated by using 1,000 random draws with coefficients and standard errors listed in Table 1. In general, all the mean values of the marginal effects of a 1% log export tax are similar in both deterministic and stochastic simulations. In the following analysis, we use the results of the stochastic simulations.

Prices and quantities

We estimate the market impacts under two (2006 and 2012) scenarios. Using 2006 as the baseline scenario, we find that the burden of the log export tax is nearly equally distributed between Russian log producers and foreign log buyers.[6] Specifically, each 1% increase in log export tax increases the equilibrium log export price by 0.52% and reduces the equilibrium price in the domestic market by 0.48%. As indicated in Fig. 1b, the incidence of log export tax does not change with the tax rate, as it is determined by the relative values of log excess supply and excess demand elasticities. Thus, when the log export tax is 25%, equilibrium domestic log price drops by 12%, and equilibrium log export price increases by 13%.

[6] The nearly equally distributed tax burden suggests that the elasticities of export supply and export demand for logs are approximately equal in absolute value. Using parameter values in Table 1 and Eq. (19), we have the export supply elasticity ε_{end}^G = 0.50. With $\eta_E^G = 0.41$, we get $\frac{\tilde{P}_E^G}{\tau} = 0.55$ and $\frac{\tilde{P}^G}{\tau} = -0.45$ according to Eqs. (13′) and (14′), which are the same results as the determinate simulation of 2006 scenario in Table 4.

Table 3
Estimation results of parameters.

	$\ln D^L$		$\ln D^L_E$		$\ln D^G_E$		$\ln S^G$		$\ln I$	
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
$\ln P$	−0.21**	−0.19*	−0.32**	−0.51***	−0.41***	−0.41***	0.12	0.32	0.40***	0.39***
	(0.09)	(0.10)	(0.12)	(0.16)	(0.11)	(0.13)	(0.20)	(0.27)	(0.10)	(0.10)
$\ln Q_{t-1}$	−0.71***	0.71***	1.10***	1.15***	0.82***	0.82***	0.49	0.42	0.28*	0.29**
	(0.10)	(0.09)	(0.07)	(0.08)	(0.09)	(0.08)	(0.30)	(0.32)	(0.14)	(0.13)
$\ln Q_{t-2}$	na	na	na	na	na	na	na	na	0.38**	0.38***
									(0.14)	(0.13)
Constant	5.80***	5.65***	0.07	0.21	4.73**	4.73***	8.55*	9.00*	0.66	0.78
	(1.76)	(1.42)	(0.83)	(0.87)	(1.70)	(1.63)	(4.69)	(4.63)	(1.54)	(1.39)
R^2	0.75	0.75	0.96	0.96	0.85	0.85	0.30	0.29	0.77	0.77
ARCH	0.51		0.12		0.68		3.76*		0.03	
H-test[a]	0.02		0.00		3.61*		0.45		5.08**	
R^2 (1st stage)		0.94		0.77		0.86		0.87		0.98
Durbin[b]		0.78		1.96		0.00		1.43		1.02
Wu-Hausman		0.81		2.29		0.00		1.76		0.82
Overidentify		9.18		4.28				6.05		

Note: Authors' estimations. *** $P<0.01$; ** $P<0.05$; * $P<0.10$. The standard errors (S.E.) are in the parentheses under each coefficient. ARCH is the LM test for autoregressive conditional heteroscedasticity with the null hypothesis of no ARCH effects. H-test[a] is Durbin's H-test for autocorrelation with the null hypothesis of no serial correlation. Durbin[b] is the Durbin test of endogeneity for the 2SLS estimation.

Table 4
Marginal effects of a 1% log export tax on the percentage changes in prices and quantities.

	Baseline = 2006 ($k_1=0.34$, $k_2=0.47$)			Baseline = 2012 ($k_1=0.35$, $k_2=0.77$)		
	Deterministic Simulation	Stochastic Simulation		Deterministic Simulation	Stochastic Simulation	
		Mean	95% CI		Mean	95% CI
$\tilde{P}^G$	−0.45	−0.48	(−0.72, −0.28)	−0.21	−0.23	(−0.38, −0.13)
$\tilde{P}^G_E$	0.55	0.52	(0.28, 0.72)	0.79	0.77	(0.62, 0.87)
$\tilde{D}^G$	0.14	0.14	(0.06, 0.23)	0.06	0.07	(0.03, 0.12)
$\tilde{D}^G_E$	−0.22	−0.21	(−0.31, −0.10)	−0.32	−0.31	(−0.44, −0.18)
$\tilde{S}^G$	−0.05	−0.04	(−0.10, 0.03)	−0.02	−0.02	(−0.05, 0.02)
$\tilde{P}^L$	−0.34	−0.28	(−0.44, −0.17)	−0.16	−0.14	(−0.22, −0.08)
$\tilde{D}^L$	0.07	0.06	(0.02, 0.11)	0.03	0.03	(0.01, 0.05)
$\tilde{D}^L_E$	0.11	0.12	(0.05, 0.21)	0.05	0.06	(0.02, 0.11)
$\tilde{S}^L$	0.10	0.10	(0.04, 0.16)	0.04	0.05	(0.02, 0.08)
$\tilde{P}^I$	0.04	0.09	(−0.01, 0.21)	0.02	0.04	(−0.01, 0.11)
$\tilde{I}$	0.02	0.02	(−0.00, 0.04)	0.01	0.01	(−0.00, 0.02)

Note: Authors' simulations. Confidence intervals (CI) listed use 1000 random draws.

The fall in Russian log price promotes its domestic lumber production, as expected. The equilibrium quantity of domestic log demand in lumber production goes up by 0.14% under a 1% log export tax. Both lumber producers and consumers benefit from decreases in domestic log price. Each 1% increase in the tax reduces equilibrium lumber price by 0.28%. Moreover, at the equilibrium level, domestic and export demand for Russian lumber increase by 0.06% and 0.12%, respectively.

Even though equilibrium quantity of domestic log demand increases, the equilibrium quantity of Russian log supply decreases with the log export tax. Each 1% log export tax decreases equilibrium log supply by 0.04%, but this effect is not significantly different from 0 at the 5% level as reflected by its 95% confidence interval (shown in Table 4). Overall, with an isolated 1% increase in log export tax, the equilibrium demand for, and the price of, processing services increase by 0.02% and 0.09%, respectively.

Note that the simulated results are sensitive to the parameter k_2, domestic demand share of logs. This is apparent under the 2012 scenario. In 2012, 77% of Russian logs was consumed domestically. In the last three columns of Table 4, we present the marginal effects of a 1% log export tax when $k_1=0.35$ and $k_2=0.77$. A 1% log export tax increases equilibrium lumber supply by 5%, which is much lower than the 10% level under the 2006 scenario. In other words, the effectiveness of a log export tax on promoting domestic lumber production decreases with domestic demand share of logs. Compared to the 0.48% decrease under the 2006 scenario, the equilibrium price of logs in domestic market goes down only by 0.23% when there is 1% log export tax in 2012, which in turn has a smaller impact on domestic lumber production.

Welfare distribution

The welfare effects calculated with the mean values of stochastic simulations are reported in Table 5. Since the tax rate varied between 2007 and 2012, we calculate the welfare changes in each period separately using 2006 baseline values. Overall, the equilibrium domestic price of and total demand for Russian logs decrease with the imposition of the log export tax. Therefore, Russian log producers suffered. The percentage change in welfare increases with the rate of the ad valorem export tax. Total welfare loss to Russian log producers was US $2.85 billion between January 2007 and July 2012, which was a 21% decrease compared to the 2006 level. Meanwhile, total welfare loss to ROW log buyers was US $1.63 billion, which was 23% of its initial equilibrium welfare level in 2006.

On the other hand, Russian lumber producers and consumers benefited from the log export tax. Specifically, domestic lumber consumers gained more than domestic lumber producers (US $0.4 billion vs. US $0.14 billion). As about two-thirds of Russian lumber were exported, foreign lumber buyers benefited about twice (US $0.8 billion) as much as Russian domestic lumber consumers.

Table 5
Welfare effects based on stochastic simulations (baseline = 2006).

	$\tau = 0.065$		$\tau = 0.20$		$\tau = 0.25$		Total	
	%	US $ million	%	US $ million	%	US $ million	%	US $ million
Period	Jan 1, 07–June 30, 07		July 1, 07–Mar 31, 08		Apr 1, 08–July 31, 12		Jan 1, 07–July 31, 12	
Welfare distribution for Russia								
ΔCS^L	3.65	10.77	11.29	49.91	14.13	360.95	12.81	421.62
ΔPS^G	−6.19	−73.53	−18.98	−338.36	−23.70	−2440.99	−21.49	−2852.88
ΔPS^I	1.16	3.48	3.57	16.08	4.47	116.18	4.05	135.74
TR		80.96		363.05		2593.62		3037.63
Sum		21.68		90.67		629.76		742.11
Welfare distribution for foreign consumers								
ΔCS_E^G	−6.76	−42.67	−20.50	−194.15	−25.49	−1394.76	−23.15	−1631.57
ΔCS_E^L	3.66	20.60	11.35	95.82	14.23	694.06	12.90	810.49
Sum		−22.07		−98.32		−700.69		−821.08
Deadweight loss		−0.39		−7.65		−70.93		−78.97

Note: Authors' calculations. Percentage changes of welfare are compared to their initial equilibrium values in 2006. The welfare changes in foreign market only account for Russian exports to the international market and do not cover the rest-of-the-world domestic log and lumber markets.

Together, foreign buyers of Russian logs and lumber lost US $0.8 billion.

Finally, Russian government gained tax revenue of US $3.04 billion, which was big enough to cover the welfare loss to its log producers. In aggregate, Russia benefited from the log export tax, with a net gain of US $0.74 billion between January 2007 and July 2012.

In sum, with the log export tax, Russia was able to benefit at the expense of foreign log buyers. Domestically, there was also a welfare transfer from log producers to lumber producers, lumber consumers, and Russian treasury. Foreign buyers as a whole lost for Russia's national interest. The total deadweight loss was about US $79 million, which increases with the export tax rate.

Conclusions

In this paper, we develop a vertical log-lumber market model to estimate the effects of Russian log export tax. Our model covers two products and three markets. We specify the demand for Russian logs to be constrained by lumber production and the ROW buyers and estimate, for the first time, several parameters for Russian log and lumber markets. Using these parameters, we find that the incidence of Russian log export tax on log prices is nearly equally distributed between Russian log producers and foreign log buyers, with foreign log buyers bearing 52% of the tax burden. While Russian logging sector suffered from the log export tax, the country as a whole benefited with a welfare gain of US $742 million between January 2007 and July 2012. This means that the loss in its logging sector is transferred to domestic lumber producers, domestic lumber consumers, and Russian treasury. Foreign buyers of Russian lumber gained about twice that of domestic lumber consumers, although the benefits to foreign lumber buyers are not sufficient to compensate for the losses of foreign log buyers in the study period. Compared to the impact of this 25% tax rate, Russia's total welfare gains and lumber sector gains might have been reduced since 2013 when it moved to a tariff-rate quota system that has a 13 to 15% export tax within quota and 25% afterwards. On the other hand, while Russian treasury receive less tax revenues, its logging sector may receive some quota rent under the new regime. While these results cannot be directly compared to Solberg et al. (2010) which has a different focus, they differ from van Kooten and Johnston (2014) which use different parameters and possibly double count the quasi-rents to logs in their total welfare estimation.

From a national perspective, Russia succeeded by imposing an export tax on softwood logs between 2007 and 2012, owing to its dominant position as a log exporter and ability to discriminate against foreign log buyers. The problem is that an export tax on logs may not be effective enough for Russia to promote its wood processing sector. The net gain to lumber industry is the quasi-rents to processing services (Eq. (22)). A welfare increase in lumber sector requires logs and processing inputs to be gross complements in lumber production ($|\eta| > \sigma$, which means a greater overall demand elasticity for lumber than elasticity of substitution between inputs. Only in this case, imposing an export tax on logs increases the demand for and price of processing inputs. However, as shown in our stochastic simulations, the demand and price increases (Table 4) are not sufficiently enough to generate much of a gain for the lumber sector (Table 5). If the policy goal is to stimulate lumber industry, a better strategy might be to subsidize the sector of processing services directly.

The Muth-type EDM makes transparent the determinate economic forces of tax incidence. However, a limitation of this partical equilibrium analysis lies in that changes in all other markets are constrained. It should be made clear that the welfare simulations will be far from certain with increasing tax rate. This is a typical trade-off with assumed linearity in the relevant ranges of supply and demand curves in welfare calculations. We caution anyone to extend this estimated result of a specific tax policy to a larger tax rate or other jurisdictions. Furthermore, our theoretical analysis highlights the need for careful elucidation of the elasticity values. Of special concern is the export demand elasticity for the finished good (lumber), as it implicates the tax incidence and thus the welfare from the tax. Econometric efforts to update and refine elasticity estimates should have a large payoff in predicting and explaining the efficacy of this policy instrument.

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