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Research article

Assessing the spatial effects of economic freedom on forest-products, grazing-land, and cropland footprints: The case of Asia-Pacific countries

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ABSTRACT

The literature has shown that economic freedom yields higher economic growth. However, the nexus between economic freedom and the environment in a world of spatial dependency is unclear. Using data from a panel of seventeen Asia-Pacific countries from 2000 to 2017, we investigate the direct and spillover effects of economic freedom (as measured by the annual indexes developed by the Heritage Foundation) and other variables on the ecological footprint of three land-cover types: cropland, forest products, and grazing land. Diagnostic tests confirm the existence of spatial-interaction effects in forest products and grazing land but reject it for cropland. Using a spatial Durbin panel model, we find that the intensity of energy use has a significant impact on the environmental footprint of all resource types. We also confirm the environmental Kuznets curve hypothesis for forest products and grazing land but not cropland. Unlike previous researchers, we find cropland footprints are unaffected by natural resource rents. We also find that the tax burden is the only economic freedom indicator with a positive and significant impact on all three environmental footprints. Our findings suggest that more investment freedom reduces environmental pressure on cropland and forest-products footprints but has a nonsignificant effect on the grazing-land footprint. Further, financial freedom reduces the forest-products footprint and increases the grazing-land footprint. Property rights, the tax burden, and business freedom increase environmental pressure while government spending lessens grazing land's ecological footprint. Our indirect and overall impact analyses suggest that all types of economic freedom reduce environmental strain in our panel. This research points to the importance of enacting environmental regulations in a way that guarantees ecological sustainability and economic development.

1. Introduction

Environmental challenges have attracted the attention of environmental and natural resource economists. Economic activities stimulate demand for food and services and encourage energy consumption, together lowering environmental quality. There are dynamic linkages among economic growth, energy consumption, urbanization, natural resources, economic freedom, and the ecological footprint. The ecological footprint measures various anthropogenic activities such as those pertaining to cropland, oceans and fishing grounds, grazing land, developed infrastructure land, forest products, and the carbon footprint. The ecological footprint is computed in worldwide hectares of land required to manufacture goods and absorb their byproducts and waste (Ahmed and Wang, 2019).

Economic growth has been linked to environmental degradation. Rapid economic development—which includes industrialization, urbanization, and population growth—has stimulated demand for goods and services. It has put pressure on the energy sector, primarily through the transportation sector and through the use of oil products such as gasoline. The transportation sector accounts for approximately 90% of energy consumption and is responsible for producing a quarter of global CO_2 emissions (IEA, 2017).

The World Bank estimates an economic growth rate of 5.6% in 2021 worldwide. The United States' and China's economies are expected to have each contributed close to one-quarter of the world's economic growth in 2021. The United States' 2021 economic growth is expected to

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have reached 6.8% while China's economy, with continuous growth in 2020 during the pandemic, was forecasted to have grown at by 8.5% (World Bank, 2021). This economic growth resulted in higher external demand for goods and services and thereby higher commodity prices and higher energy demand. China is the largest energy consumer, and the United States the second largest. Increased external demand raises global demand for food, energy, materials, agricultural land, industrial lots, and tourist destinations, which further degrades the environment. Higher commodity prices encourage natural resource exporters to increase natural resource extraction to accommodate the demand, thereby exacerbating internal and external environmental degradation.

While most research on the ecological footprint examines the impacts of GDP, energy consumption, urbanization, natural resource rents, and trade openness (see Ahmed et al., 2020; Alola et al., 2019; Doytch, 2020; Ekeocha, 2021; Kassouri and Altıntaş, 2020; Sharma et al., 2020; Wang et al., 2013), a few studies have investigated the notion that economic freedom increases ecological footprints through three major channels: trade regulations, efficiency, and stability (see, for example, Barro, 1991; De Haan and Sturm, 2000; Gwartney et al., 1999; Islam, 1996; Panayotou, 1997). In the trade-regulatory channel, trade liberalization encourages nations with many capital-intensive industries to specialize in filthy sectors. This is known as the pollution-haven hypothesis. In the efficiency channel, economic freedom increases market efficiency and competitiveness, leading to reduced resource consumption. Efficient market economies also are governed by regulations, mainly environmental ones, that encourage consumers to purchase goods and services manufactured in cleaner ways. This implies that economic freedom can improve the environment by reducing the ecological footprint. In the stability channel, economic freedom assists in stabilizing the environment over time, in turn allowing investors to make investment decisions more confidently. The ecological footprint will increase if a country's industrial mix is more resource intensive (Antweiler et al., 2001).

The literature on the impact of economic development, energy consumption, urbanization, natural resource rents, and trade openness on the ecological footprint is growing but mixed in its findings: researchers have found positive, negative, and nonsignificant relationships (Lawson et al., 2020; Santiago et al., 2020). While a few researchers studying ecological footprints include economic freedom variables in their analyses, the literature mostly ignores their dynamic and spatial nature. Economic freedom indexes evaluate the degree of global collaboration among individuals, organizations, and economies. To measure economic freedom, this study follows the Heritage Foundation's classifications: market openness, the size of government, rule of law, and regulatory efficiency (Heritage Foundation, 2022).

Little is known about the nexus between economic freedom and the environment in a world of spatial dependency (Mushtaq and Ali Khan, 2018). We examine the environmental effects of economic freedom on the ecological footprint of three land-cover types: cropland, forest products, and grazing land. We control for economic growth, energy intensity, natural resource rents, and urbanization in seventeen Asia-Pacific countries from 2000 to 2017. We employ the spatial econometric modeling approach to assess the spatial dependency of determinants of ecological footprints.

This paper contributes to the empirical literature on environmental quality in two ways. First, it improves our understanding of economic freedom and environmental quality by studying the ecological footprint of different land-cover types as a proxy for environmental quality, unlike previous studies, which use CO_2 emissions as a proxy (Akadiri et al., 2019; Bello et al., 2018; Charfeddine, 2017; Destek and Sinha, 2020; Al-Silefanee et al., 2022; Karimi et al., 2022). Second, we use a spatial econometric technique since traditional analytic methods often ignore geographical dependency, resulting in biased results. Dependency means one country affects the countries and areas to which it is adjacent (You and Lv, 2018).

The remainder of the paper is structured as follows. Section 2 provides a brief overview of recent literature on the relationship between various indicators and the ecological footprint. Section 3 summarizes our data and empirical estimation methods. Section 4 presents the empirical results of the spatial econometric models. Section 5 concludes.

2. Literature review

The literature on environmental distortions and climate change is rapidly growing. It includes studies that measure the degree to which human activities (for example, natural resource exploration and harvesting, deforestation) produce pollution, validating the environmental Kuznets curve (EKC) hypothesis that economic development results in environmental degradation. The EKC hypothesis indicates that an inverted U-shaped curve describes the relationship between environmental degradation and economic growth.[1]

We discuss ecological-footprint indicators—including cropland, forest products, and grazing land—and their impacts on economic growth, energy consumption, urbanization, natural resource rents, and economic freedom.

2.1. Economic growth and environmental quality

Economic growth enables development, increases social welfare, and thus reduces poverty. However, it and many other economic activities have contributed to the degradation of the environment worldwide. For example, China's economic growth since the 2000s has improved the quality of life of its people. This significant improvement has come at the cost of the environment. According to Zameer et al. (2020), China's economic growth has increased energy demand and resulted in an energy shortage. It has made the country the largest carbon emitter and the country with the largest ecological footprint (Guo et al., 2019).

Danish et al. (2019) argues that economic growth and the industrialization and urbanization that accompany it encourage more consumption and extraction of natural resources. The excessive use of resources results in environmental unsustainability in the form of environmental degradation, massive waste (solid and industrial), and air-related problems (Danish. and Khan, 2020; Mamkhezri et al., 2020). By conducting a time-series analysis, Lee and Yoo (2016) assess the short- and long-run causality between CO_2 emissions (as a proxy for environmental quality) and economic growth in Mexico from 1971 to 2007 and find unidirectional causality. Yang et al. (2021) investigates the effect of economic growth and other determinants of industrialization and globalization on the ecological footprint and health expenditure among the ten countries with the highest health care spending from 1995 to 2018. The study finds bidirectional causality between health care expenditure and the ecological footprint and unidirectional causality between economic development and the ecological footprint. Danish et al. (2019) assesses fifty-nine Belt and Road Initiative countries from 1990 to 2016 and finds a causal link between economic development and environmental quality: the higher the economic growth, the more polluted the environment, and hence the larger the ecological footprint.

Scholars dispute whether the EKC hypothesis is true. Mrabet et al. (2017) studies the hypothesis by using the ecological footprint as a proxy for environmental quality in Qatar from 1980 to 2011. The study finds that in the long run, economic growth degrades environmental quality. Charfeddine and Mrabet (2017) investigate the impact of

[1] Grossman and Krueger (1995) were the pioneers in examining various air pollutants along with other indicators of environmental quality. Given the negative consequences of climate change and other challenges, the hypothesis has been broadly examined and approved or disapproved since then; see, for example, Ahmed et al. (2020), Akadırı et al. (2021), Khezri et al. (2021), Tian et al. (2021), Mamkhezri et al. (2022), and Dai et al. (2022).

economic growth on the ecological footprint in fifteen Middle East and North Africa (MENA) countries and confirm the EKC hypothesis but only for the oil-exporting countries in the region. Other studies, such as Dogan and Inglesi-Lotz (2020) and Ozturk and Acaravci (2010), disconfirm the EKC hypothesis.

2.2. Energy consumption and environmental quality

Energy has been long identified as a critical input in the production process as well as a key to sustainable economic growth. The impact of energy on economic growth has long been investigated (Benkraiem et al., 2019; Stern, 2019; Tugcu and Topcu, 2018). The contribution of energy consumption to environmental degradation is notable for many reasons. First, as conveyed in the 2021 Glasgow summit, high levels of CO_2 emission have put humankind and the environment at significant risk of irreversible harm. Second, the energy consumption of China and Pakistan represents a crucial challenge. The excessive economic growth of these countries has led to a shortage of energy worldwide (Baz et al., 2020; Wei et al., 2020). Third, the lack of adequate rules and regulations against polluting activities in developing countries has exacerbated ecological footprints (Sarkodie and Strezov, 2018). Therefore, the energy sector will rely more on fossil fuels and remain a key contributor to climate change. It produces significant waste, disrupts the environment by emitting CO_2 and other deadly pollutants (for example, methane and SO_2), and increases our dependency on natural resources.

The impact of energy consumption on the ecological footprint has also been examined. Baz et al. (2020) establishes that energy use in Pakistan from 1971 to 2014 was responsible for degrading the environment. Destek and Sinha (2020) investigate twenty-four OECD countries from 1980 to 2013 and find that increasing nonrenewable energy use degrades the environment, whereas increasing renewable energy consumption reduces the ecological footprint.

Despite the growth of renewable energy use, most industrialized countries still use dirty energy sources such as oil, natural gas, and coal. Such energy sources are responsible for world pollution. Reducing the world's dependency on fossil fuels might help mitigate environmental degradation. Scholars suggest various ways to reduce this dependency—namely, economic diversification, expansion of renewable energy use, and technological innovation (Kuriqi et al., 2019; Muhamad et al., 2021).

2.3. Urbanization and environmental quality

The ultimate purpose of almost all economic activities is economic growth, which comes along with urbanization and industrialization (Danish et al., 2019). Urbanization and industrialization might stimulate extraction of natural resources and thereby degrade the environment.

Research on the effect of urbanization on environmental quality reaches different results. Nathaniel (2021) examines South Africa and finds that urbanization, economic growth, and natural resource rents harm the environment. Charfeddine and Mrabet (2017) assess MENA countries and find that urbanization has a positive long-term impact on the environment. Karimi et al. (2022) examines the economic factors affecting the ecological footprint of the fishing sector and finds that urbanization has no significant effect.

2.4. Natural resource rents and environmental quality

Natural resource rents have critical environmental implications, but the literature on the subject has found mixed results.

Danish et al. (2019, 2020) reports the drastic extraction of natural resources in developing countries with the hope of new resource discoveries. Such countries' aggressive investment in natural resources has exacerbated pollution. Ahmed et al. (2020) examines the dynamic linkages among natural resource rents, economic growth, urbanization, human capital, and the ecological footprint from 1970 to 2016 in China. The study shows that increases in natural resource rents increased China's environmental footprint.

Danish et al. (2019) investigates the impact of the abundance of natural resource use on CO_2 emissions using data from 1990 to 2015 in Brazil, Russia, India, China, and South Africa (BRICS). The study finds that while natural resource abundance contributed to emissions in South Africa, it reduced them in Russia. Khan et al. (2020) studies the effect of technological innovations and natural resource use in the energy-growth environment between 1985 and 2014 in BRICS countries and finds that CO_2 emissions impact natural resources adversely after controlling for technological innovation. Zafar et al. (2019) finds a negative impact of the amount of natural resources on the ecological footprint after controlling for energy consumption and economic growth in the United States from 1970 to 2015. Karimi et al. (2022) finds no significant effect of natural resource rents on the ecological footprint of the fishing sector in Asia-Pacific countries over the 2000–2017 period.

2.5. Economic freedom and environmental quality

Economic freedom is often seen as an essential factor in achieving economic growth, but while economic growth improves social welfare, it also stimulates demand for food and infrastructure. As a result, such intensive activities by either the public or private sector increase the ecological footprint.

Scholars sharply disagree about the extent to which economic freedom contributes to the ecological footprint. Some argue that the market economy helps achieve environmental sustainability (for example, Roy and Goll, 2014; Mahmood et al., 2022). Others claim that the market economy's private-profit mechanism inevitably encourages resource extraction and pollution (Karimi et al., 2022; Özler and Obach, 2009). Governments and private agents are increasingly being held accountable for their activities. Therefore, government intervention in the form of environmental regulation is seen as necessary to control pollution and incentivize the development of advanced technologies to solve environmental issues (Rapsikevicius et al., 2021; Roy and Goll, 2014). While such regulations may mitigate emissions, more economic freedom is also likely to stimulate green technological development (Bjørnskov, 2020).

Using panel data for BRICS economies from 1995 to 2018, Akadırı et al. (2021) assesses the EKC hypothesis within the framework of economic freedom. The study finds that economic freedom, in the long run, harms the environment. Shahnazi and Dehghan Shabani (2021) discover a U-shaped (rather than an inverted U-shaped) relationship between economic freedom and CO_2 emissions in European countries using data from 2000 to 2017. Karimi et al. (2022) investigates how economic freedom, through various channels, increases the fishing-grounds footprint. Ghiţă et al. (2019) finds a significant and positive impact of economic freedom, the educational level of the labor force, and the development of renewable energy sources on the ecological footprint. Majeed et al. (2021) investigates the dynamic impacts of economic freedom on Pakistan's economic development and air quality from 1990 to 2019. The study finds that economic freedom has no effect on pollution in the short run but decreases it in the long run.

Economic freedom comprises several components, such as government integrity, property rights, trade openness, the tax burden, government expenditure, and business and investment freedom. The literature on the relationships among these components and their impact on the environment reaches mixed results. Uzar (2021) finds that institutional quality reduced the ecological footprint in the E−7 countries from 1992 to 2015. Xie and Wang (2019) study China's fast-growing public spending from 2006 to 2015 and highlight a positive effect of the spending on environmental protection. Zhou and Segerson (2012) investigate Connecticut and find that environmental taxes can significantly improve social welfare by improving environmental quality. Mamkhezri (2019, 2020a, 2020b, 2021) assesses the environmental and economic impacts of environmentally motivated renewable-portfolio-standard policies in New Mexico and finds that these policies can improve the environment and that the public favors them. Ozturk et al. (2016) examines the relationship between trade openness and the ecological footprint in 144 countries from 1988 to 2008. The study reports a positive relationship in upper-middle- and high-income countries.

3. Methodology and data

3.1. Empirical model

This study employs a spatial econometric model to examine the effect of economic freedom on forest-products, grazing-land, and cropland footprints in Asia-Pacific nations. The model takes into account the geographical interdependence of the determinants of ecological footprints. It builds on Carlsson and Lundström's (2003) and Danish et al.'s (2020) empirical ecological-footprint models. Our empirical model is

$$lnEFP_{it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP^2_{it} + \beta_4 lnENER_{it} + \beta_5 lnURB_{it} + \beta_6 lnRENT_{it} + \beta_7 lnFree_{it} + c_i + \alpha_t + \upsilon_{it} \quad (1)$$

Our dependent variable, an index of the ecological footprint per capita, is a function of various exogenous variables: GDP per capita (*lnGDPP*), trade openness (*lnOPE*), energy intensity (*lnENER*), natural resource rents (*lnRENT*), urbanization (*lnURB*), and economic freedom indexes (*lnFree*). These variables are all in logarithmic form; thus, their coefficients should be interpreted as elasticities. α_t are time-specific intercepts that capture heterogeneity across periods, and c_i are country-specific intercepts that capture heterogeneous factors across countries such as differences in political and economic conditions, different institutional infrastructures, and sociodemographic factors, among others. As indicated by Baltagi (2005), excluding time-specific and country-specific intercepts in cross-sectional and time-series studies may skew the results.

The EKC hypothesis illustrates how economic progress affects environmental sustainability. According to it, when economic growth is considered as an independent variable, environmental degradation has an inverted U-shape. As the economy expands, environmental degradation first increases, then gradually decreases (Grossman and Krueger, 1995; Lee and Yoo, 2016). Therefore, we include a squared term of GDP, which we expect to have a negative sign if the hypothesis holds (that is, $\beta_3 < 0$).

As for urbanization, Tsuchiya et al. (2021) shows that it, population growth, and aging all have exacerbated Japan's per capita food ecological footprint. If China and many other developing countries moved into the second stage of urbanization, this would increase infrastructure development, industrial production, and demand for natural resources and thus environmental degradation. While many developing countries are in the second stage of urbanization, developed countries are already in the third stage (Ahmed et al., 2020). Thus, we include urbanization as an exogenous variable.

Because each country's variables impact those of adjacent countries, we use three spatial panel data sets to examine the regional effects of our independent variables. That includes a lagged dependent variable, an autoregressive spatial process in the residual term (Anselin et al., 2008), and the spatial Durbin model, which incorporates the impacts of a neighboring country's exogenous variable on the dependent variable in a nested manner (LeSage and Pace, 2009). The spatial-lag model is as follows:

$$y_{it} = \lambda \sum_{j=1}^{N} w_{ij} y_{jt} + x_{it}\beta + c_i + \alpha_t + \upsilon_{it} \quad (2)$$

Here, x is a $1 \times K$-dimensional vector of exogenous variables corresponding to countries $i = 1, ..., N$ during periods $t = 1,...,T$; and β is a $K \times 1$ vector of parameters. The dependent variable is y_{it}. $\sum_{j=1}^{N} w_{ij} y_{jt}$ represents the influence of the dependent variable in surrounding countries on the dependent variable in a reference country. w_{ij} is the $i, j - th$ element of an $N \times N$ spatial-weights matrix w. Before matrix standardization, the $i, j - th$ element takes the value of one of two neighboring countries or zero if two countries are not neighbors. The random error term is denoted by υ_{it}.

u_{it} is the spatial-error model and consists of a residual term of unit i that is dependent on the residual terms for surrounding countries u_{jt}, a spatial-weights matrix W, and an idiosyncratic component, υ_{it}:

$$y_{it} = \lambda \sum_{j=1}^{N} w_{ij} y_{jt} + x_{it}\beta + c_i + \alpha_t + u_{it}$$
$$u_{it} = \rho \sum_{j=1}^{N} w_{ij} u_{jt} + \upsilon_{it} \quad (3)$$

The spatial Durbin model also incorporates into the spatial-lag model lagged exogenous variables that vary spatially:

$$y_{it} = \lambda \sum_{j=1}^{N} w_{ij} y_{jt} + x_{it}\beta + \sum_{j=1}^{N} w_{ij} x_{jt}\theta + c_i + \alpha_t + \upsilon_{it} \quad (4)$$

Here, $\sum_{j=1}^{N} w_{ij} x_{jt}$ represents the interactions between the exogenous variables x_{ijt} in nearby countries and the dependent variable y_{it} in a particular country. θ is a $K \times 1$ vector of parameters.

3.2. Data

We collected data on seventeen Asia-Pacific countries from 2000 to 2017: Australia, China, Indonesia, South Korea, Malaysia, Japan, Thailand, Vietnam, Bangladesh, India, Mongolia, Nepal, Pakistan, the Philippines, Russia, Singapore, and Sri Lanka. Table 1 provides an overview of our parameters. Table 2 provides descriptive statistics for the parameters. We use nine freedom indexes developed by the Heritage Foundation: (1) *Property rights* refers to an individual's ability to develop their property and wealth. (2) *Government integrity* refers to the degree to which a government combats its institutions' systemic corruption in such forms as bribery, cronyism, nepotism, embezzlement, patronage, and graft. (3) The *tax burden* refers to the fiscal constraints governments impose on economic activity (including tariffs and sales, payroll, excise, and value-added taxes). (4) *Government expenditure* refers to a government's size, expense, and invasiveness. (5) *Business freedom* is an entity's ability to create and run a business without excessive governmental interference. (6) *Monetary freedom* refers to price stability and the lack of price controls. (7) *Trade freedom* indicates the absence of tariff and nontariff barriers. (8) *Investment freedom* indicates the absence of restrictions (for individuals and businesses) on the flow of investment funds. (9) *Financial freedom* refers to the ability of individuals to make life choices without being unduly concerned about the choices' financial consequences. Fig. 1 maps the total economic freedom index in the studied countries. None of the countries are global outliers, and all fall between the twenty-fifth and seventy-fifth percentiles of the index range.

We investigate the impact of each index on each dependent variable—forest-products, grazing-land, and cropland footprints—in eleven estimations. All estimations include such control variables as the logarithms of GDP per capita (in level and squared forms), energy intensity, resource rents, and urbanization. As shown in Table 1, Estimation 1 only contains the control variables; Estimation 2 also includes the total economic freedom variable, which is the sum of the nine indicators. We inserted the nine indexes of economic freedom in separate estimations to analyze their independent influence while avoiding collinearity among the indexes.

To avoid cluttering our results tables (Tables 3–5), we use the term *lnFREE* for all economic freedom indexes; it refers to the corresponding index. For example, *lnFREE* in Estimations 11 and 5 refers to the

Table 1
Variables' notation, construction, and source.

Variable	Variable constructed	Included in	Source
$lnCF_{it}$	$lnCF_{it} = log(CF_{it})$ CF_{it} = Cropland footprint		GFN
$lnFPF_{it}$	$lnFPF_{it} = log(FPF_{it})$ FPF_{it} = Forest-products footprint		GFN
$lnGLF_{it}$	$lnGLF_{it} = log(GLF_{it})$ GLF_{it} = Grazing-land footprint		GFN
$lnGDPP_{it}$	$lnGDPP_{it} = log(GDPP_{it})$ $GDPP_{it}$ = GDP per capita (2010 USD)	All estimations	WDI
$lnENER_{it}$	$lENER_{it} = \log(ENER_{it})$ $ENER_{it}$ = Energy-intensity level of primary energy	All estimations	WDI
$lnURB_{it}$	$lnURB_{it} = \log(URB_{it})$ URB_{it} = Urban population (% of the total population)	All estimations	WDI
$lnRENT_{it}$	$lnRENT_{it} = log(RENT_{it})$ $RENT_{it}$ = Total natural resource rents (% of GDP)	All estimations	WDI
$lnEFI_{it}$	$lnEFI_{it} = log(EFI_{it})$ EFI_{it} = Total economic freedom	Estimation 2	Heritage
$lnPRI_{it}$	$lnPRI_{it} = log(PRI_{it})$ PRI_{it} = Property rights	Estimation 3	Heritage
$lnGII_{it}$	$lnGII_{it} = log(GII_{it})$ GII_{it} = Government integrity	Estimation 4	Heritage
$lnTBI_{it}$	$lnTBI_{it} = log(TBI_{it})$ TBI_{it} = Tax burden	Estimation 5	Heritage
$lnGSI_{it}$	$lnGSI_{it} = log(GSI_{it})$ GSI_{it} = Government spending	Estimation 6	Heritage
$lnBFI_{it}$	$lnBFI_{it} = log(BFI_{it})$ BFI_{it} = Business freedom	Estimation 7	Heritage
$lnLMF_{it}$	$lnLMF_{it} = log(LMF_{it})$ LMF_{it} = Monetary freedom	Estimation 8	Heritage
$lnTFI_{it}$	$lnTFI_{it} = log(TFI_{it})$ TFI_{it} = Trade freedom	Estimation 9	Heritage
$lnIFI_{it}$	$lnIFI_{it} = log(IFI_{it})$ IFI_{it} = Investment freedom	Estimation 10	Heritage
$lnFFI_{it}$	$lnFFI_{it} = log(FFI_{it})$ FFI_{it} = Financial freedom	Estimation 11	Heritage

World Development Indicator (WDI): www.datacatalog.worldbank.org/dataset/world-.
Global Footprint Network (GFN): www.footprintnetwork.org/resources/data/.
Heritage Foundation (Heritage): www.heritage.org/index/.

logarithms of financial freedom and the tax burden, respectively. The reader should refer to Table 1 to ascertain which measure of economic freedom is employed in each estimation.

4. Estimations and analysis

We conduct several diagnostic tests to determine the optimal panel model for each land-cover type. We use two likelihood ratio (LR) tests to assess the likelihood of time-period and geographical fixed effects in our estimations. The LR test results are summarized in Appendix Table A1. If the null hypotheses are rejected, it implies the need to use a panel model that incorporates both spatial fixed effects and time-period fixed effects; otherwise, either the time-fixed-effects or spatial-fixed-effects model is appropriate. The null hypotheses are rejected for most estimations; however, we fail to reject it for spatial effects in cropland and grazing land. Therefore, the optimal panel models include spatial fixed effects for cropland and grazing land and simultaneous spatial and time-period fixed effects for forest products.

We conduct the Lagrange multiplier (LM) test to determine whether spatial-interaction effects exist when a spatial lag or spatial inaccuracy is included. The LM test's rejection of the null hypothesis confirms the existence of both the spatial-lag model and the spatial-error model. The LM test results for the spatial-lag and spatial-error models are summarized in Appendix Tables A2 and A3, respectively. Taking into account the regional effects for cropland and grazing land (discussed above), the tests reject the existence of spatial error in all estimations for these variables; however, the presence of spatial lags cannot be ruled out. We find somewhat comparable findings for forest products, as we confirm the presence of a spatial lag in the model with simultaneous spatial and time-period fixed effects.

To determine whether the spatial Durbin model can be condensed into the spatial-error model and the spatial-lag model, we perform Wald and LR tests on Equation (4) to examine the following two null hypotheses: $H_0: \theta + \lambda\beta = 0$ for the former and $H_0: \theta = 0$ for the latter. The test results are summarized in Appendix Tables A4 and A5. In all estimations except the cropland one, the Wald test results are significant, indicating that the spatial Durbin model cannot be converted into a spatial-error or spatial-lag model. Therefore, the spatial Durbin model with a regionally lagged independent variable is the optimal model to evaluate the findings from the forest-products and grazing-land estimations.

Finally, we perform the Hausman test to investigate the potential to substitute a random-effects model for the fixed-effects model. Our test results are summarized in Appendix Table A6. This test's null hypothesis posits the presence of random effects. We reject the null hypothesis for cropland and grazing land at the 1% significance level and fail to reject the null for forest products. Therefore, we include random effects only

Table 2
Descriptive statistics of variables.

Variable	Mean	Median	Maximum	Minimum	Std. dev.	Observations
$lnCF_{it}$	3.780	3.757	4.925	2.783	0.368	306
$lnFPF_{it}$	3.096	2.999	4.824	2.058	0.662	306
$lnGLF_{it}$	1.731	1.886	6.308	−1.654	1.758	306
$lnGDPP_{it}$	8.389	8.120	10.957	6.121	1.443	306
$lnENER_{it}$	1.660	1.685	2.533	0.657	0.384	306
$lnURB_{it}$	3.840	3.840	4.605	2.595	0.539	306
$lnRENT_{it}$	0.060	0.840	3.819	−8.075	2.802	306
$lnEFI_{it}$	4.091	4.044	4.493	3.777	0.170	306
$lnPRI_{it}$	3.743	3.912	4.500	2.303	0.553	306
$lnGII_{it}$	3.548	3.466	4.543	1.386	0.531	306
$lnTBI_{it}$	4.320	4.329	4.517	3.987	0.114	306
$lnGSI_{it}$	4.359	4.419	4.557	3.666	0.177	306
$lnBFI_{it}$	4.173	4.217	4.605	3.570	0.238	306
$lnLMF_{it}$	4.322	4.331	4.546	3.661	0.117	306
$lnTFI_{it}$	4.216	4.285	4.500	2.976	0.240	306
$lnIFI_{it}$	3.726	3.807	4.500	1.609	0.495	306
$lnFFI_{it}$	3.763	3.689	4.500	2.303	0.373	306

Note: *GDPP* = *GDP* per capita; *ENER* = energy intensity level of primary energy; *URB* = urban population; *RENT* = natural resource rents; *EFI* = economic freedom; *PRI* = property rights; *GII* = government integrity; *TBI* = tax burden; *GSI* = government spending; *BFI* = business freedom; *MFI* = monetary freedom; *TFI* = trade freedom; *IFI* = investment freedom; *FFI* = financial freedom.

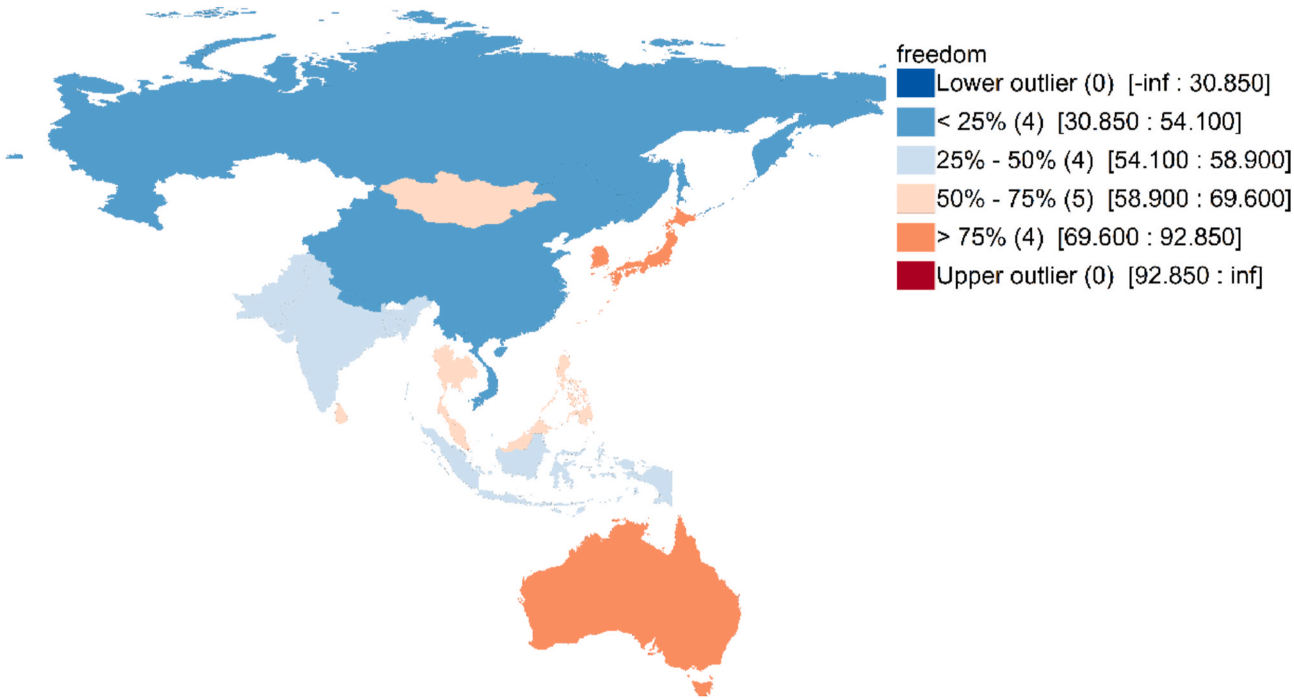

Fig. 1. Total economic freedom index.

Table 3
Estimation results for cropland footprint.

	Est. A1	Est. A2	Est. A3	Est. A4	Est. A5	Est. A6	Est. A7	Est. A8	Est. A9	Est. A10	Est. A11
lnGDPP	0.598	0.582	0.595	0.644	0.558	0.639	0.596	0.600	0.704	0.494	0.621
	(0.032)	(0.038)	(0.032)	(0.021)	(0.044)	(0.024)	(0.032)	(0.030)	(0.018)	(0.080)	(0.028)
$lnGDPP^2$	−0.015	−0.014	−0.014	−0.016	−0.015	−0.018	−0.015	−0.015	−0.020	−0.009	−0.017
	(0.366)	(0.401)	(0.387)	(0.341)	(0.354)	(0.290)	(0.350)	(0.350)	(0.244)	(0.600)	(0.329)
lnENE	0.186	0.183	0.173	0.201	0.169	0.177	0.172	0.176	0.186	0.198	0.183
	(0.050)	(0.054)	(0.073)	(0.035)	(0.074)	(0.065)	(0.073)	(0.064)	(0.049)	(0.036)	(0.053)
lnRENT	−0.012	−0.011	−0.009	−0.008	−0.011	−0.013	−0.014	−0.015	−0.012	−0.015	−0.012
	(0.453)	(0.506)	(0.618)	(0.636)	(0.513)	(0.425)	(0.410)	(0.368)	(0.471)	(0.378)	(0.480)
lnURB	0.039	0.037	0.048	−0.051	0.086	0.035	0.034	0.019	0.036	0.023	0.033
	(0.808)	(0.821)	(0.766)	(0.774)	(0.596)	(0.828)	(0.831)	(0.905)	(0.822)	(0.886)	(0.839)
lnFREE		0.078	0.037	0.050	0.220	−0.077	0.050	−0.105	−0.054	−0.044	0.020
		(0.656)	(0.417)	(0.189)	(0.056)	(0.425)	(0.412)	(0.261)	(0.320)	(0.069)	(0.616)
$W\times x$	−0.226	−0.235	−0.222	−0.242	−0.238	−0.229	−0.240	−0.231	−0.219	−0.230	−0.239
	(0.011)	(0.009)	(0.013)	(0.007)	(0.007)	(0.010)	(0.008)	(0.009)	(0.014)	(0.010)	(0.007)

Note: P-values are in parentheses; Est. = Estimation. Estimated Equation (5): $lnCF_{it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP_{it}^2 + \beta_4 lnENER_{it} + \beta_5 lnURB_{it} + \beta_6 lnRENT_{it} + \beta_7 lnFree_{it} + \lambda \sum_{j=1}^{N} w_{ij}CF_{jt} + c_i + \upsilon_{it}$, where *GDP* = *GDP* per capita; *ENER* = energy-intensity level of primary energy; *URB* = urban population; *RENT* = natural resource rents; $W\times x$ = interaction between dependent and exogenous variables; *FREE* = economic freedom. *lnFREE* stands for *lnEFI, lnPRI, lnGII, lnTBI, lnGSI, lnBFI, lnLMF, lnPTF, lnIFI,* and *lnFFI* in Estimations 2 to 11, respectively.
Source: Authors' estimations.

for forest products. As our diagnostic test results show that each type of land cover leads to a different spatial econometric model, we do not include all three land-cover types in a single model.

Our diagnostic tests reveal the following:

- The optimal model for the cropland footprint incorporates spatial fixed effects, spatial lags, and panel fixed effects.
- The optimal model for the grazing-land footprint incorporates spatial fixed effects, spatial lags, a spatial Durbin model with a regionally lagged independent variable, and panel fixed effects.
- The optimal model for the forest-products footprint incorporates spatial lags, simultaneous spatial and time fixed effects, a spatial Durbin model with a regionally lagged independent variable, and panel random effects.

We estimate the following equations for cropland, forest-products, and grazing-land footprints, respectively:

$$lnCF_{it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP_{it}^2 + \beta_4 lnENER_{it} + \beta_5 lnURB_{it} + \beta_6 lnRENT_{it} + \beta_7 lnFree_{it} + \lambda \sum_{j=1}^{N} w_{ij}CF_{jt} + c_i + \upsilon_{it} \quad (5)$$

Table 4
Estimation results for forest-products footprint.

	Est. B1	Est. B2	Est. B3	Est. B4	Est. B5	Est. B6	Est. B7	Est. B8	Est. B9	Est. B10	Est. B11
lnGDPP	1.960	1.938	2.114	1.932	1.765	2.026	1.984	1.768	1.856	1.193	1.650
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnGDPP^2	−0.055	−0.053	−0.067	−0.055	−0.046	−0.058	−0.055	−0.046	−0.049	−0.015	−0.041
	(0.001)	(0.002)	(0.000)	(0.001)	(0.006)	(0.001)	(0.001)	(0.010)	(0.011)	(0.373)	(0.028)
lnENE	0.235	0.260	0.192	0.227	0.177	0.194	0.241	0.247	0.233	0.323	0.324
	(0.050)	(0.029)	(0.109)	(0.059)	(0.131)	(0.110)	(0.054)	(0.037)	(0.052)	(0.005)	(0.008)
lnREN	−0.091	−0.096	−0.098	−0.090	−0.088	−0.084	−0.091	−0.099	−0.090	−0.091	−0.087
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnURB	−0.757	−0.756	−0.721	−0.690	−0.619	−0.747	−0.776	−0.772	−0.754	−0.654	−0.700
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnFREE		−0.137	0.015	−0.037	0.463	−0.078	−0.034	−0.256	0.032	−0.114	−0.145
		(0.453)	(0.759)	(0.383)	(0.001)	(0.481)	(0.630)	(0.022)	(0.614)	(0.000)	(0.003)
W × *lnGDPP*	1.221	1.143	1.136	1.226	1.523	1.114	1.166	0.360	0.853	−0.957	0.096
	(0.133)	(0.154)	(0.163)	(0.131)	(0.067)	(0.171)	(0.150)	(0.670)	(0.422)	(0.252)	(0.920)
W × *lnGDPP*^{2}	0.012	0.015	0.007	0.009	0.003	0.018	0.017	0.057	0.033	0.133	0.065
	(0.775)	(0.726)	(0.880)	(0.831)	(0.947)	(0.683)	(0.697)	(0.204)	(0.571)	(0.003)	(0.182)
W × *lnENE*	−0.959	−0.800	−0.858	−0.958	−0.774	−0.987	−0.889	−1.041	−1.005	−0.605	−0.805
	(0.007)	(0.023)	(0.014)	(0.007)	(0.026)	(0.006)	(0.013)	(0.003)	(0.006)	(0.073)	(0.022)
W × *lnREN*	−0.116	−0.152	−0.094	−0.111	−0.159	−0.051	−0.106	−0.131	−0.114	−0.061	−0.070
	(0.072)	(0.018)	(0.144)	(0.084)	(0.012)	(0.503)	(0.105)	(0.046)	(0.083)	(0.317)	(0.277)
W × *lnURB*	−3.579	−3.507	−3.399	−3.439	−3.946	−3.649	−3.727	−2.835	−3.529	−2.767	−2.798
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.002)
W × *lnFREE*		−1.693	−0.348	−0.054	−0.390	0.443	−0.300	−0.570	0.113	−0.391	−0.104
		(0.001)	(0.004)	(0.617)	(0.326)	(0.064)	(0.163)	(0.022)	(0.631)	(0.000)	(0.364)
W × *x*	−0.316	−0.303	−0.304	−0.323	−0.233	−0.296	−0.291	−0.404	−0.319	−0.422	−0.335
	(0.001)	(0.001)	(0.001)	(0.001)	(0.011)	(0.001)	(0.002)	(0.000)	(0.001)	(0.000)	(0.000)
θ	0.030	0.029	0.030	0.030	0.027	0.030	0.030	0.030	0.030	0.031	0.033
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: P-values are in parentheses; Est. = Estimation. Estimated Equation (6): $lnFPF_{it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP_{it}^2 + \beta_4 lnENER_{it} + \beta_5 lnURB_{it} + \beta_6 lnRENT_{it} + \beta_7 lnFree_{it} + \lambda \sum_{j=1}^{N} w_{ij} FPF_{jt} + \sum_{j=1}^{N} w_{ij} x_{jt}\theta + c_i + \upsilon_{it}$, where *GDP* = *GDP* per capita; *ENER* = energy-intensity level of primary energy; *URB* = urban population; *RENT* = natural resource rents; *FREE* = economic freedom; $W \times x$ = interaction between dependent and exogenous variables; and θ is a K × 1 vector of parameters. *lnFREE* stands for *lnEFI*, *lnPRI*, *lnGII*, *lnTBI*, *lnGSI*, *lnBFI*, *lnLMF*, *lnPTF*, *lnIFI*, and *lnFFI* in Estimations 2 to 11, respectively.
Source: Authors' estimations.

$$lnFPF_{it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP_{it}^2 + \beta_4 lnENER_{it} + \beta_5 lnURB_{it} + \beta_6 lnRENT_{it} + \beta_7 lnFree_{it} + \lambda \sum_{j=1}^{N} w_{ij} FPF_{jt} + \sum_{j=1}^{N} w_{ij} x_{jt}\theta + c_i + \upsilon_{it} \tag{6}$$

$$lnGLF_{it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP_{it}^2 + \beta_4 lnENER_{it} + \beta_5 lnURB_{it} + \beta_6 lnRENT_{it} + \beta_7 lnFree_{it} + \lambda \sum_{j=1}^{N} w_{ij} GLF_{jt} + \sum_{j=1}^{N} w_{ij} x_{jt}\theta + c_i + \alpha_t + \upsilon_{it} \tag{7}$$

Table 3 summarizes the results for the eleven estimations of the cropland footprint using the optimal panel models. Our findings suggest that each percentage-point rise in GDP per capita results in an increase of around 0.6% in cropland's ecological footprint. This means that economic development exacerbates the ecological footprint of cropland. The nonsignificant coefficient of squared GDP per capita demonstrates that we cannot confirm an inverted U-shaped relationship between economic growth and the cropland footprint. Among the other control variables, only energy intensity, a measure of energy efficiency, is positive and significant, indicating that a decrease in energy efficiency leads to environmental deterioration in cropland areas. Therefore, higher use of clean renewable energy can alleviate environmental pressure on croplands in our panel. Only Estimations 5 and 10 show significant coefficients for economic freedom indexes. These estimations correspond to the tax burden and investment freedom, with a positive coefficient for the former and a negative coefficient for the latter. This means that a lower tax burden and higher investment freedom both reduce cropland's footprint. More efficient entrepreneurial activities and less constrained capital movement, as well as lower taxation of such activities and movements, lead to more efficient use of cropland.

Table 4 summarizes the results for the forest-products footprint. Our findings indicate that both the level and squared forms of GDP per capita have a significant effect on the forest-products footprint and show the correct signs. Our estimations find a positive coefficient for GDP per capita and a negative coefficient for GDP per capita squared; therefore, we confirm the EKC hypothesis for the forest-products footprint. Each percentage-point increase in GDP per capita increases the forest-products footprint by roughly 2%. This indicates that economic prosperity increases the footprint of forest products at a decreasing rate. The coefficient of energy intensity is positive and significant, indicating that increased energy efficiency and clean energy use enable the forest-products industry to reduce environmental strain. Resource rents and urbanization have negative and significant effects of −0.091 and −0.757, respectively, indicating that both natural resource extraction and urbanization lower the environmental pressure from forest products. These results seem counterintuitive; however, both processes have nearly reached saturation levels in the Asia-Pacific countries. For example, approximately half the population there resided in urban areas in 2020 (United Nations, 2013). Hence, higher urbanization lowers environmental pressure of forest products in rural areas. Similarly, as these economies grow, natural resource–extraction intensity tapers increasingly to the extent that it may even zero out (−0.091).

We find that monetary freedom, investment freedom, and financial freedom have negative and significant effects while the tax burden has positive and significant effects. Monetary freedom is measured as the average inflation rate in the past decade. Its negative coefficient suggests that lower inflation rates in the assessed countries lessen the forest-products footprint. Meanwhile, investment freedom, financial freedom, and a lower tax burden encourage entrepreneurial activities that allocate resources more efficiently. The negative and significant

Table 5
Estimation results for grazing-land footprint.

	Est. C1	Est. C2	Est. C3	Est. C4	Est. C5	Est. C6	Est. C7	Est. C8	Est. C9	Est. C10	Est. C11
lnGDPP	3.003	2.563	3.388	3.017	2.700	3.259	2.621	3.319	2.686	2.950	2.875
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)
$lnGDPP^2$	−0.062	−0.030	−0.079	−0.061	−0.053	−0.082	−0.048	−0.080	−0.045	−0.059	−0.057
	(0.200)	(0.533)	(0.092)	(0.203)	(0.274)	(0.089)	(0.319)	(0.111)	(0.390)	(0.246)	(0.250)
lnENE	1.311	1.133	1.085	1.287	1.189	1.133	1.253	1.241	1.282	1.323	1.202
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnREN	−0.289	−0.264	−0.271	−0.268	−0.272	−0.301	−0.291	−0.305	−0.289	−0.286	−0.273
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnURB	−1.698	−1.652	−1.628	−1.590	−1.435	−1.599	−1.580	−1.798	−1.675	−1.707	−1.619
	(0.000)	(0.000)	(0.000)	(0.002)	(0.003)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
lnFREE		1.878	0.745	−0.043	0.832	−0.810	0.443	−0.142	0.174	−0.043	0.217
		(0.000)	(0.000)	(0.690)	(0.019)	(0.004)	(0.016)	(0.632)	(0.274)	(0.540)	(0.058)
W× *lnGDPP*	−7.539	−6.656	−9.471	−7.658	−7.046	−7.316	−7.505	−7.097	−7.900	−7.715	−7.894
	(0.000)	(0.002)	(0.000)	(0.000)	(0.002)	(0.001)	(0.000)	(0.002)	(0.001)	(0.001)	(0.000)
W× $lnGDPP^2$	0.545	0.493	0.673	0.528	0.530	0.519	0.532	0.534	0.567	0.551	0.554
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
W× *lnENE*	0.527	0.632	1.084	0.413	0.805	0.591	1.026	0.539	0.475	0.464	0.323
	(0.446)	(0.344)	(0.097)	(0.545)	(0.249)	(0.385)	(0.146)	(0.445)	(0.491)	(0.512)	(0.639)
W× *lnREN*	0.187	0.154	0.248	0.073	0.167	0.200	0.131	0.216	0.190	0.189	0.143
	(0.019)	(0.069)	(0.001)	(0.400)	(0.036)	(0.012)	(0.109)	(0.009)	(0.019)	(0.027)	(0.084)
W× *lnURB*	−4.776	−5.332	−4.557	−3.678	−5.136	−4.321	−4.043	−5.532	−5.002	−4.539	−4.309
	(0.011)	(0.004)	(0.010)	(0.050)	(0.006)	(0.027)	(0.031)	(0.006)	(0.008)	(0.018)	(0.024)
W× *lnFREE*		−2.235	−0.375	−0.695	−0.789	0.424	0.820	0.564	0.033	0.060	−0.441
		(0.078)	(0.187)	(0.002)	(0.363)	(0.381)	(0.097)	(0.181)	(0.943)	(0.741)	(0.037)
W× *x*	−0.148	−0.151	−0.092	−0.163	−0.142	−0.141	−0.170	−0.154	−0.143	−0.151	−0.127
	(0.110)	(0.100)	(0.309)	(0.075)	(0.125)	(0.128)	(0.068)	(0.097)	(0.122)	(0.103)	(0.167)

Note: P-values are in parentheses; Est. = Estimation. Estimated Equation (7): $lnGLF_{it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP_{it}^2 + \beta_4 lnENER_{it} + \beta_5 lnURB_{it} + \beta_6 lnRENT_{it} + \beta_7 lnFree_{it} + \lambda \sum_{j=1}^{N} w_{ij} GLF_{jt} + \sum_{j=1}^{N} w_{ij} x_{jt} \theta + c_i + \alpha_t + \upsilon_{it}$, where *GDP* = *GDP* per capita; *ENER* = energy-intensity level of primary energy; *URB* = urban population; *RENT* = natural resource rents; *W* × *x* = interaction between dependent and exogenous variables; and *FREE* = economic freedom. *lnFREE* stands for *lnEFI*, *lnPRI*, *lnGII*, *lnTBI, lnGSI, lnBFI, lnLMF, lnPTF, lnIFI,* and *lnFFI* in Estimations 2 to 11, respectively.
Source: Authors' estimations.

coefficients of investment freedom and financial freedom and the positive and significant coefficient of the tax burden suggest that increasing investment freedom and financial freedom and reducing tax burdens lower the pressure on forest-products land cover. The Asia-Pacific countries should foster economic freedom through lower taxes and inflation and higher investment and financial freedoms to reduce the forest-products footprint.

Table 5 summarizes our regression results for the grazing-land-footprint estimations. The effects of the control variables are comparable to those for the forest-products footprint, except that the coefficient of squared GDP per capita is nonsignificant and thus we cannot confirm the EKC hypothesis for grazing land. Our interpretation of these variables for grazing land is similar to that for forest products. We find positive and significant results for property rights, the tax burden, business freedom, and financial freedom, which implies a positive and significant impact of total economic freedom on the grazing-land footprint. Government spending has a negative and significant effect on the grazing-land footprint. Therefore, restrained government spending and a lower tax burden (that is, smaller government size) can lead to higher private economic activities, which can lower the grazing-land footprint. Our results also indicate that business and financial freedoms, property rights, and total economic freedom increase the grazing-land footprint. Therefore, if Asia-Pacific countries aim to reduce their grazing lands' ecological footprint, we encourage them to lower government expenditure and taxation. However, we caution against promoting other economic freedoms such as property rights, business freedom, and financial freedom, as they exacerbate the grazing-land footprint.

Spatial panel models enable us to separate variables' total effects into direct and spillover effects. Direct effects quantify the effect of exogenous variables on a country's dependent variable. Spillover effects evaluate the impact of exogenous variables in nearby countries on a reference country's dependent variable. For each of our dependent variables, Tables 6–8 show the total, direct, and spillover effects of the common parameters in Estimation 1 and the effects of the economic freedom indexes in Estimations 2–11. To avoid cluttering this section, we refrain from interpreting all forty-five elasticity points (direct, indirect, and total effects of fifteen exogenous variables) reported in Tables 6–8

According to our findings as summarized in Table 6, the spillover effects of neighboring countries' determinants of the reference country's cropland footprint are mostly nonsignificant. GDP per capita, with a negative spillover effect, is the only determinant that is even marginally significant (p-value = 0.105). These findings are consistent with our first diagnostic tests, indicating that the drivers of cropland's footprint are not spatial. A 1% increment in GDP per capita in the reference country increases its cropland footprint by 0.6%. If GDP per capita in the neighboring countries rises by 1%, the cropland footprint in the reference country decreases by only 0.11%. A 1% increase in GDP per capita in both the reference country and neighboring countries causes a 0.49% increase in the reference country's cropland footprint. Energy intensity shows positive and marginally significant direct and total impacts on the reference country's cropland footprint. This variable does not have a significant spillover effect. Among the economic freedom variables, only the tax burden and investment freedom affect the cropland footprint directly, although both are only marginally significant. These findings again suggest that the Asia-Pacific countries ought to lower taxes and increase investment freedom to reduce the cropland footprint. All the economic freedom indicators have negative but nonsignificant spillover and overall effects.

Table 7 reports the overall, direct, and spillover effects for the fifteen determinants of the forest-products footprint. Our findings indicate that nine determinants show significant direct effects and twelve have significant indirect and total effects. The economic freedom indicators all show negative and significant spillover effects. A one-percentage-point

Table 6
Marginal effects of cropland-footprint determinants.

	Direct		Indirect (spillover)		Total	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
$lnGDPP_{it}$	0.606	(0.042)	−0.114	(0.105)	0.492	(0.045)
$lnGDPP^2_{it}$	−0.015	(0.369)	0.003	(0.417)	−0.013	(0.371)
$lnENER_{it}$	0.189	(0.078)	−0.034	(0.123)	0.155	(0.089)
$lnURB_{it}$	−0.013	(0.446)	0.002	(0.491)	−0.011	(0.445)
$lnRENT_{it}$	0.042	(0.795)	−0.009	(0.776)	0.033	(0.803)
$lnEFI_{it}$	0.085	(0.637)	−0.008	(0.810)	−0.009	(0.536)
$lnPRI_{it}$	0.036	(0.452)	−0.007	(0.819)	−0.006	(0.667)
$lnGII_{it}$	0.051	(0.207)	0.008	(0.833)	−0.006	(0.645)
$lnTBI_{it}$	0.219	(0.080)	−0.017	(0.624)	−0.008	(0.532)
$lnGSI_{it}$	−0.083	(0.407)	−0.007	(0.818)	−0.011	(0.443)
$lnBFI_{it}$	0.051	(0.425)	−0.009	(0.810)	−0.010	(0.460)
$lnLMF_{it}$	−0.104	(0.297)	−0.005	(0.885)	−0.011	(0.411)
$lnTFI_{it}$	−0.052	(0.366)	−0.009	(0.801)	−0.010	(0.508)
$lnIFI_{it}$	−0.045	(0.086)	−0.006	(0.858)	−0.012	(0.408)
$lnFFI_{it}$	0.023	(0.582)	−0.008	(0.813)	−0.010	(0.496)

Note: P-values are in parentheses. GDPP = GDP per capita; ENER = energy-intensity level of primary energy; URB = urban population; RENT = natural resource rents; EFI = economic freedom; PRI = property rights; GII = government integrity; TBI = tax burden; GSI = government spending; BFI = business freedom; MFI = monetary freedom; TFI = trade freedom; IFI = investment freedom; FFI = financial freedom.
Source: Authors' estimations.

Table 7
Marginal effects of forest-products-footprint determinants.

	Direct		Indirect (spillover)		Total	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
$lnGDPP_{it}$	1.923	(0.000)	0.517	(0.459)	2.439	(0.002)
$lnGDPP^2_{it}$	−0.056	(0.006)	0.023	(0.536)	−0.033	(0.356)
$lnENER_{it}$	0.280	(0.028)	−0.825	(0.010)	−0.544	(0.112)
$lnURB_{it}$	−0.087	(0.002)	−0.072	(0.173)	−0.158	(0.009)
$lnRENT_{it}$	−0.614	(0.004)	−2.716	(0.001)	−3.330	(0.000)
$lnEFI_{it}$	−0.074	(0.692)	−2.626	(0.002)	−0.190	(0.004)
$lnPRI_{it}$	0.030	(0.532)	−2.610	(0.001)	−0.151	(0.017)
$lnGII_{it}$	−0.035	(0.409)	−2.570	(0.002)	−0.153	(0.016)
$lnTBI_{it}$	0.486	(0.002)	−3.224	(0.000)	−0.202	(0.003)
$lnGSI_{it}$	−0.107	(0.354)	−2.787	(0.001)	−0.105	(0.140)
$lnBFI_{it}$	−0.024	(0.736)	−2.876	(0.001)	−0.151	(0.016)
$lnLMF_{it}$	−0.230	(0.062)	−1.946	(0.010)	−0.163	(0.009)
$lnTFI_{it}$	0.027	(0.672)	−2.669	(0.002)	−0.152	(0.020)
$lnIFI_{it}$	−0.093	(0.003)	−1.909	(0.007)	−0.108	(0.041)
$lnFFI_{it}$	−0.141	(0.010)	−2.034	(0.012)	−0.117	(0.051)

Note: P-values are in parentheses. *GDPP* = GDP per capita; *ENER* = energy-intensity level of primary energy; *URB* = urban population; *RENT* = natural resource rents; *EFI* = economic freedom; *PRI* = property rights; *GII* = government integrity; *TBI* = tax burden; *GSI* = government spending; *BFI* = business freedom; *MFI* = monetary freedom; *TFI* = trade freedom; *IFI* = investment freedom; *FFI* = financial freedom.
Source: Authors' estimations.

increase in economic freedom in neighboring countries reduces the environmental pressure from forest products in the reference country by 2%–3%, depending on which of the indexes is used. All nine economic freedom indicators (property rights, government integrity, the tax burden, government spending, business freedom, monetary freedom, trade freedom, investment freedom, and financial freedom) reduce the forest-products footprint by 0.1%–0.2%. These results indicate that the spillover and total effects of economic freedom are useful tools for the studied Asia-Pacific countries. Mahmood et al. (2022) finds similar results. Improved energy efficiency, increased resource rents, and urbanization in neighboring countries have marginally significant impacts on a reference country's reliance on forest products.

Table 8 summarizes these three effects for the determinants of the grazing-land footprint. Our estimations indicate that urbanization in surrounding countries increases a reference country's grazing-land footprint. Neighboring countries' higher natural resource extraction lowers the reference country's grazing-land footprint. The positive coefficient of GDP per capita in neighboring countries and the negative coefficient of its squared term indicate that increased GDP per capita reduces a country's grazing-land footprint at a decreasing rate. We find comparable spillover effects for economic freedom in the grazing-land-footprint estimations to those for the forest-products footprint. Our results suggest that a one-percentage-point increase of economic freedom in neighboring countries alleviates the environmental pressure exerted by grazing lands in a reference country by 3.1%–4.6%, depending on the economic freedom index. Government integrity, business freedom, and financial freedom lower the grazing-land footprint by approximately 0.14%. The remaining economic freedom indicators have negative signs and are marginally significant. Economic freedom's indirect and overall effects show that it can alleviate pressure from grazing lands in the studied Asia-Pacific countries.

5. Conclusion and policy implications

Using data from a panel of seventeen Asia-Pacific countries from 2000 to 2017, we investigated the direct, spillover, and total effects of several determinants of cropland, forest-products, and grazing-land footprints. We performed various diagnostic tests to discover the

Table 8
Marginal effects of grazing-land-footprint determinants.

	Direct		Indirect (spillover)		Total	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
$lnGDPP_{it}$	3.176	(0.001)	−7.203	(0.002)	−4.027	(0.064)
$lnGDPP_{it}^2$	−0.076	(0.129)	0.500	(0.000)	0.424	(0.001)
$lnENER_{it}$	1.297	(0.000)	0.286	(0.642)	1.582	(0.033)
$lnURB_{it}$	−0.297	(0.000)	0.210	(0.010)	−0.087	(0.173)
$lnRENT_{it}$	−1.580	(0.004)	−4.021	(0.033)	−5.602	(0.007)
$lnEFI_{it}$	1.922	(0.001)	−4.514	(0.013)	−0.100	(0.151)
$lnPRI_{it}$	0.753	(0.000)	−4.098	(0.031)	−0.022	(0.756)
$lnGII_{it}$	−0.025	(0.810)	−3.068	(0.083)	−0.166	(0.020)
$lnTBI_{it}$	0.849	(0.024)	−4.464	(0.020)	−0.093	(0.122)
$lnGSI_{it}$	−0.827	(0.009)	−3.606	(0.061)	−0.091	(0.144)
$lnBFI_{it}$	0.428	(0.033)	−3.383	(0.060)	−0.137	(0.043)
$lnLMF_{it}$	−0.182	(0.559)	−4.567	(0.020)	−0.078	(0.220)
$lnTFI_{it}$	0.175	(0.284)	−4.235	(0.026)	−0.084	(0.199)
$lnIFI_{it}$	−0.042	(0.552)	−3.799	(0.042)	−0.082	(0.244)
$lnFFI_{it}$	0.220	(0.071)	−3.814	(0.045)	−0.121	(0.075)

Note: P-values are in parentheses. *GDPP* = GDP per capita; *ENER* = energy-intensity level of primary energy; *URB* = urban population; *RENT* = natural resource rents; *EFI* = economic freedom; *PRI* = property rights; *GII* = government integrity; *TBI* = tax burden; *GSI* = government spending; *BFI* = business freedom; *MFI* = monetary freedom; *TFI* = trade freedom; *IFI* = investment freedom; *FFI* = financial freedom.
Source: Authors' estimations.

optimal modeling approach for estimating those footprints. Our tests failed to reject the presence of spatial-interaction effects in the case of forest products and grazing land and rejected their presence in the case of cropland. We used spatial fixed effects to investigate cropland and grazing land and a model that considers both spatial and time-period fixed effects to assess the forest footprint in our panel. Our analysis consists of several regression models executed in sequence to find evidence regarding the impact of economic freedom on the ecological footprints of cropland, forest products, and grazing land in Asia-Pacific countries.

We found that the intensity of energy use (as a measure of production efficiency) has a significant effect on the ecological footprint of cropland, forest products, and grazing land, indicating that optimizing production procedures and efficiency provides additional tools and facilities for extracting and producing agricultural products more efficiently. Our findings corroborate those of Majeed et al. (2021) and Usman et al. (2021), whose studies demonstrate that fossil fuel energy consumption reduces environmental quality in panels of countries. Moreover, the current energy mix of our panel of countries is detrimental to the ecological footprint of our three studied types of land cover. These findings suggest that governments should focus on increasing the production of renewable energy. An implication is that updating environmental regulations in accordance with the 2021 Glasgow summit to mitigate CO_2 emissions further can help these countries limit polluting activities.

Our findings confirm the EKC hypothesis for forest products and grazing land but not for cropland. The significance of the GDP-per-capita coefficient suggests that during the initial stages of economic growth, the advent of new technology for harvesting resources and lifting consumption standards increases resource extraction. The significance of the GDP-per-capita-squared parameter for forest products and grazing land demonstrates the concave nature of the relationship: natural resource–extraction intensity diminishes progressively as the economy grows, to the extent that it may even reach zero in these two sectors. However, economic growth has resulted in a continuous increase in cropland's ecological footprint, indicating that the EKC hypothesis for cropland is invalid.

Urbanization enables rural-to-urban migration, which lessens the environmental strain of forest products and grazing land in rural areas. This is consistent with prior studies by Chikaraishi et al. (2015) and Dodman (2009). Tsuchiya et al. (2021) verifies that urbanization has had no substantial influence on cropland resources. Natural resource rents, which aggravate all ecological-footprint indicators in most previous studies, exerted no significant effect on the cropland footprint in our panel of countries. The growth of rents to natural resources, such as oil and natural gas, has the potential to generate extra revenues for local governments. This would provide incentives for production and alleviate economic strain on other resources. Our results demonstrate that the accessibility of earned revenue from other resources results in a nonsignificant decrease in environmental pressure from cropland. Further, clean energy deployment, resource rents, and urbanization in adjacent countries lead reference countries to reduce their dependence on forest products and grazing lands. We advise the Asia-Pacific countries to enact energy-efficiency policies and deploy renewable energy sources to lower forest-product and grazing-land footprints.

The most robust finding regarding the economic freedom indicators is that the tax burden has a direct, positive, and significant impact on all the ecological-footprint parameters. This is to be expected, as a higher tax burden increases governments' income share and lowers individuals' willingness to work. Lowering the tax burden can lead to more efficient resource allocation by entrepreneurs, reducing ecological footprints of the assessed types of land cover.

Higher investment freedom decreases environmental pressure on the cropland and forest-products sectors, while it has a nonsignificant impact on the grazing-land footprint. Investment freedom means there are no restrictions on the flow of investment capital. A free and open investment environment fosters entrepreneurship and incentivizes economic activity. The negative coefficients of this indicator in our estimations suggest that the environmental benefits of investment freedom outweigh its disadvantages. Our results complement those of Liu et al. (2018), Solarin and Al-Mulali (2018), and Zafar et al. (2019), all of which demonstrate a negative relationship between economic freedom and the ecological footprint. These findings highlight that the Asia-Pacific countries should endorse entrepreneurial activities through imposing fewer restrictions on investment. Such policies would lead to more efficient allocation of resources, increasing productivity and in turn reducing environmental strain.

We also found that cropland is unaffected by financial independence. However, financial independence impacts forest products and grazing land differently: it has a negative impact on the former and a positive effect on the latter. A well-functioning formal financial system that is accessible and efficient guarantees that people and companies have access to a diverse range of savings, credit, payment, and investment services. Financial independence fosters economic growth and alleviates environmental degradation by boosting efficiency, shifting production toward higher-tech manufacturing of commodities, and avoiding the manufacturing of raw materials. Our findings suggest that the impact of improving efficiency and productivity is more significant for forest products, but the effect of increasing economic growth is more significant for grazing land. Higher financial freedom is advisable for countries that aim to reduce their forest-products footprint, while lower financial freedom may be advisable for countries that aim to reduce their grazing-land footprint.

Monetary freedom does not affect forest output but does alleviate the sector's environmental pressures. With a monetary system that aims to combat inflation, citizens can expect market prices to remain stable. They may gain confidence in making investments, engaging in saving, and pursuing other long-term objectives. Our findings indicate that price stability reduces real interest rates and lengthens the time until land is deforested, resulting in a reduction in environmental pressure in this sector. The studied Asia-Pacific nations are advised to maintain low inflation rates to reduce the forest-product footprint.

The grazing-land estimations' coefficients for the majority of the economic freedom variables are significant. Property rights, the tax burden, and business freedom increase environmental pressure, while government spending lessens grazing land's ecological footprint. Secure property rights instill confidence in residents, allowing them to engage in economic activities in general without worrying about arbitrary expropriation or theft. Higher tax rates degrade individuals' and businesses' ability to pursue their objectives in the market, and they decrease private sector activity. Business freedom ensures individuals can form and operate a business without excessive governmental interference, while duplicated and complex rules create obstacles to entrepreneurial activity, which increases the cost of production and reduces entrepreneurs' success. Thus, all three of these factors contribute to environmental pressure on the grazing-land footprint through increasing individual liberty and economic growth. Extreme government spending may lead to short-term economic growth, distort the allocation of resources, increase bureaucracy, lower productivity, and increase the public debt in a way that burdens future generations. Our findings demonstrate that the absence of such regulations decreases the environmental impact of grazing land through increasing efficiency and enabling a shift from raw material production.

We captured the geographic dependencies among the Asia-Pacific nations and investigated economic freedom's effects on different types of land cover. Different economic freedom indicators have different direct impacts on the ecological footprints of cropland, forest products, and grazing lands in a given country. However, our indirect and overall findings represent overwhelming evidence that all types of economic freedom—from property rights, to government integrity, to financial freedom and more—in surrounding countries alleviate environmental pressure from grazing lands and forest products in reference countries. These results suggest that economic freedom in the assessed Asia-Pacific countries lessens pressure on the environment.

The empirical literature has reached inconsistent results on the direct impacts of the various components of the economic freedom index. While some researchers have verified the beneficial impact of economic freedom on ecological footprints (Clark and Longo, 2019; Holleman, 2018; Longo and Clausen, 2011), others have highlighted its detrimental effects (Baloch et al., 2018; Sun et al., 2019). Our results offer policy makers fresh insights as they work to construct comprehensive economic and environmental policies to support long-term economic development while enhancing environmental quality. Our findings highlight that forming an overarching policy that accounts for the various characteristics of economic freedom is not easy. This study highlights the importance of enacting environmental regulations in a way that guarantees ecological sustainability and economic development. We encourage policy makers to pay particular attention to the spatial environmental impacts of economic freedom when enacting policies aimed at increasing environmental sustainability. Spatial assessments of other groups of countries, such as MENA and Europe, and individual countries are needed. Future research should include additional relevant parameters such as country-level energy-portfolio mix, agriculture's share of GDP, foreign direct investment, the Gini index, the adult literacy rate, political affiliation, and temperature in their spatial analyses.

Credit author statement

All authors contributed equally.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A1
Likelihood ratio test results

	Cropland		Forest		Grazing land	
	Spatial	Time period	Spatial	Time period	Spatial	Time period
Estimation 1	23.611	483.236	48.253	569.211	12.758	790.804
	(0.168)	(0.000)	(0.000)	(0.000)	(0.806)	(0.000)
Estimation 2	23.996	467.904	48.850	569.615	19.786	736.209
	(0.155)	(0.000)	(0.000)	(0.000)	(0.345)	(0.000)
Estimation 3	23.657	458.677	48.484	563.973	13.571	785.603
	(0.167)	(0.000)	(0.000)	(0.000)	(0.757)	(0.000)
Estimation 4	24.342	462.511	47.828	566.935	12.906	771.087
	(0.144)	(0.000)	(0.000)	(0.000)	(0.797)	(0.000)
Estimation 5	24.534	470.699	59.611	486.653	16.750	799.367
	(0.138)	(0.000)	(0.000)	(0.000)	(0.540)	(0.000)
Estimation 6	24.512	351.966	55.121	548.009	18.601	778.891
	(0.139)	(0.000)	(0.000)	(0.000)	(0.417)	(0.000)

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Table A1 (*continued*)

	Cropland		Forest		Grazing land	
	Spatial	Time period	Spatial	Time period	Spatial	Time period
Estimation 7	26.453	485.740	52.563	567.812	18.588	781.718
	(0.090)	(0.000)	(0.000)	(0.000)	(0.418)	(0.000)
Estimation 8	23.019	475.460	49.672	553.130	12.495	773.595
	(0.190)	(0.000)	(0.000)	(0.000)	(0.821)	(0.000)
Estimation 9	23.365	480.024	48.385	562.243	12.292	738.114
	(0.177)	(0.000)	(0.000)	(0.000)	(0.832)	(0.000)
Estimation 10	23.858	460.966	45.263	540.336	12.758	790.356
	(0.160)	(0.000)	(0.000)	(0.000)	(0.806)	(0.000)
Estimation 11	23.830	461.177	40.950	575.710	19.151	759.174
	(0.161)	(0.000)	(0.002)	(0.000)	(0.383)	(0.000)

Note: See Table 1 for definitions. P-values are in parentheses.
Source: Authors' estimations.

Table A2
Lagrange multiplier test results for the existence of spatial lag

		Pooled OLS		Spatial fixed effects		Time-period fixed effects		Spatial and time-period fixed effects	
Cropland	Estimation A1	5.340	(0.021)	3.272	(0.070)	6.233	(0.013)	2.357	(0.125)
	Estimation A2	5.020	(0.025)	3.357	(0.067)	5.287	(0.021)	2.382	(0.123)
	Estimation A3	8.448	(0.004)	3.153	(0.076)	7.921	(0.005)	2.286	(0.131)
	Estimation A4	5.371	(0.020)	3.649	(0.056)	5.631	(0.018)	2.503	(0.114)
	Estimation A5	4.831	(0.028)	3.587	(0.058)	4.627	(0.031)	2.189	(0.139)
	Estimation A6	11.917	(0.001)	3.285	(0.070)	15.093	(0.000)	2.377	(0.123)
	Estimation A7	6.011	(0.014)	3.527	(0.060)	7.204	(0.007)	2.307	(0.129)
	Estimation A8	3.303	(0.069)	3.273	(0.070)	3.415	(0.065)	2.199	(0.138)
	Estimation A9	3.826	(0.050)	3.059	(0.080)	4.663	(0.031)	2.405	(0.121)
	Estimation A10	8.997	(0.003)	3.335	(0.068)	8.729	(0.003)	2.417	(0.120)
	Estimation A11	3.130	(0.077)	3.332	(0.068)	4.219	(0.040)	2.408	(0.121)
Forest	Estimation B1	20.616	(0.000)	0.126	(0.723)	5.876	(0.015)	5.298	(0.021)
	Estimation B2	13.892	(0.000)	0.031	(0.860)	4.712	(0.030)	4.455	(0.035)
	Estimation B3	22.666	(0.000)	0.270	(0.603)	6.122	(0.013)	4.313	(0.038)
	Estimation B4	22.346	(0.000)	0.113	(0.737)	6.490	(0.011)	5.410	(0.020)
	Estimation B5	49.070	(0.000)	0.845	(0.358)	2.208	(0.137)	3.737	(0.053)
	Estimation B6	4.390	(0.036)	0.246	(0.620)	0.028	(0.867)	4.838	(0.028)
	Estimation B7	21.552	(0.000)	0.116	(0.733)	4.810	(0.028)	4.897	(0.027)
	Estimation B8	29.630	(0.000)	0.116	(0.734)	6.866	(0.009)	5.998	(0.014)
	Estimation B9	21.019	(0.000)	0.130	(0.718)	3.320	(0.068)	5.214	(0.022)
	Estimation B10	33.952	(0.000)	0.717	(0.397)	2.430	(0.119)	10.274	(0.001)
	Estimation B11	24.595	(0.000)	0.062	(0.804)	7.535	(0.006)	6.952	(0.008)
Grazing land	Estimation C1	10.544	(0.001)	1.921	(0.166)	10.584	(0.001)	0.343	(0.558)
	Estimation C2	3.721	(0.054)	2.949	(0.086)	3.783	(0.052)	0.550	(0.458)
	Estimation C3	5.032	(0.025)	1.847	(0.174)	4.967	(0.026)	0.199	(0.655)
	Estimation C4	1.341	(0.247)	1.927	(0.165)	1.383	(0.240)	0.356	(0.551)
	Estimation C5	11.626	(0.001)	1.867	(0.172)	11.273	(0.001)	0.203	(0.653)
	Estimation C6	29.080	(0.000)	2.747	(0.097)	27.309	(0.000)	0.254	(0.614)
	Estimation C7	4.551	(0.033)	2.601	(0.107)	4.325	(0.038)	0.541	(0.462)
	Estimation C8	4.488	(0.034)	2.056	(0.152)	4.417	(0.036)	0.459	(0.498)
	Estimation C9	8.450	(0.004)	1.958	(0.162)	7.677	(0.006)	0.343	(0.558)
	Estimation C10	9.898	(0.002)	1.874	(0.171)	9.940	(0.002)	0.350	(0.554)
	Estimation C11	0.811	(0.368)	2.551	(0.110)	0.645	(0.422)	0.438	(0.508)

Note: See Table 1 for definitions. P-values are in parentheses.
Source: Authors' estimations.

Table A3
Lagrange multiplier test results for the existence of spatial error

		Pooled OLS		Spatial fixed effects		Time-period fixed effects		Spatial and time-period fixed effects	
Cropland	Estimation A1	1.324	(0.250)	0.750	(0.386)	1.675	(0.196)	2.048	(0.152)
	Estimation A2	0.709	(0.400)	0.772	(0.380)	0.407	(0.524)	2.066	(0.151)
	Estimation A3	0.137	(0.711)	0.727	(0.394)	0.762	(0.383)	2.066	(0.151)
	Estimation A4	0.186	(0.666)	0.752	(0.386)	0.013	(0.909)	1.897	(0.168)
	Estimation A5	1.310	(0.252)	1.035	(0.309)	1.923	(0.166)	2.175	(0.140)
	Estimation A6	10.075	(0.002)	0.638	(0.424)	19.259	(0.000)	1.598	(0.206)
	Estimation A7	1.135	(0.287)	0.788	(0.375)	1.409	(0.235)	1.980	(0.159)
	Estimation A8	0.032	(0.858)	0.945	(0.331)	0.078	(0.781)	2.095	(0.148)
	Estimation A9	0.498	(0.480)	0.798	(0.372)	0.558	(0.455)	2.485	(0.115)
	Estimation A10	0.403	(0.526)	0.679	(0.410)	1.671	(0.196)	1.811	(0.178)
	Estimation A11	0.368	(0.544)	0.765	(0.382)	0.115	(0.735)	2.076	(0.150)
Forest	Estimation B1	0.064	(0.800)	0.215	(0.643)	0.982	(0.322)	0.905	(0.341)
	Estimation B2	0.093	(0.760)	0.148	(0.701)	0.999	(0.318)	0.734	(0.392)

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Table A3 (*continued*)

		Pooled OLS		Spatial fixed effects		Time-period fixed effects		Spatial and time-period fixed effects	
	Estimation B3	0.071	(0.790)	0.327	(0.567)	1.518	(0.218)	0.681	(0.409)
	Estimation B4	0.076	(0.782)	0.284	(0.594)	1.226	(0.268)	0.849	(0.357)
	Estimation B5	1.667	(0.197)	1.032	(0.310)	0.025	(0.875)	0.092	(0.761)
	Estimation B6	0.653	(0.419)	0.226	(0.634)	2.136	(0.144)	1.493	(0.222)
	Estimation B7	0.007	(0.934)	0.207	(0.649)	0.391	(0.532)	0.819	(0.365)
	Estimation B8	0.042	(0.837)	0.224	(0.636)	0.290	(0.590)	0.914	(0.339)
	Estimation B9	0.170	(0.680)	0.225	(0.635)	2.095	(0.148)	0.971	(0.324)
	Estimation B10	0.109	(0.742)	0.056	(0.813)	2.814	(0.093)	2.481	(0.115)
	Estimation B11	0.016	(0.900)	0.095	(0.758)	0.768	(0.381)	1.154	(0.283)
Grazing land	Estimation C1	31.320	(0.000)	1.006	(0.316)	33.461	(0.000)	0.679	(0.410)
	Estimation C2	3.020	(0.082)	1.140	(0.286)	6.537	(0.011)	0.638	(0.424)
	Estimation C3	22.137	(0.000)	0.816	(0.366)	27.909	(0.000)	0.391	(0.532)
	Estimation C4	11.110	(0.001)	1.001	(0.317)	13.063	(0.000)	0.596	(0.440)
	Estimation C5	38.084	(0.000)	1.171	(0.279)	40.007	(0.000)	0.863	(0.353)
	Estimation C6	39.071	(0.000)	1.403	(0.236)	40.114	(0.000)	0.333	(0.564)
	Estimation C7	31.243	(0.000)	1.643	(0.200)	33.217	(0.000)	1.302	(0.254)
	Estimation C8	13.810	(0.000)	0.980	(0.322)	16.622	(0.000)	0.751	(0.386)
	Estimation C9	22.716	(0.000)	1.151	(0.283)	24.980	(0.000)	0.823	(0.364)
	Estimation C10	30.334	(0.000)	0.961	(0.327)	32.597	(0.000)	0.714	(0.398)
	Estimation C11	12.903	(0.000)	0.721	(0.396)	13.939	(0.000)	0.484	(0.487)

Note: See Table 1 for definitions. P-values are in parentheses.
Source: Authors' estimations.

Table A4
Spatial Durbin model against spatial-lag model

	Cropland		Forest		Grazing land	
	Wald test	LR test	Wald test	LR test	Wald test	LR test
Estimation 1	9.873	9.646	80.560	79.268	70.537	66.738
	(0.079)	(0.086)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 2	12.102	12.262	90.555	89.666	84.729	78.255
	(0.060)	(0.056)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 3	10.707	10.596	89.221	87.876	107.130	95.879
	(0.098)	(0.102)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 4	10.852	10.497	80.259	79.114	81.937	76.373
	(0.093)	(0.105)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 5	15.709	15.574	76.343	81.038	73.133	68.912
	(0.015)	(0.016)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 6	11.759	11.623	74.087	74.611	64.912	61.618
	(0.068)	(0.071)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 7	11.199	11.032	76.545	77.010	75.216	70.615
	(0.082)	(0.087)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 8	9.768	9.643	98.062	86.609	70.164	66.415
	(0.135)	(0.141)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 9	9.089	8.816	81.367	79.460	70.814	66.908
	(0.169)	(0.184)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 10	10.236	9.933	102.465	101.092	71.145	67.273
	(0.115)	(0.128)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 11	10.128	9.979	71.263	71.357	73.738	69.161
	(0.119)	(0.126)	(0.000)	(0.000)	(0.000)	(0.000)

Note: See Table 1 for definitions. P-values are in parentheses.
Source: Authors' estimations.

Table A5
Spatial Durbin model against spatial-error model

	Cropland		Forest		Grazing land	
	Wald test	LR test	Wald test	LR test	Wald test	LR test
Estimation 1	9.873	9.646	80.560	79.268	70.537	66.738
	(0.079)	(0.086)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 2	12.102	12.262	90.555	89.666	84.729	78.255
	(0.060)	(0.056)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 3	10.707	10.596	89.221	87.876	107.130	95.879
	(0.098)	(0.102)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 4	10.852	10.497	80.259	79.114	81.937	76.373
	(0.093)	(0.105)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 5	15.709	15.574	76.343	81.038	73.133	68.912
	(0.015)	(0.016)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 6	11.759	11.623	74.087	74.611	64.912	61.618
	(0.068)	(0.071)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 7						

(continued on next page)

Table A5 (*continued*)

	Cropland		Forest		Grazing land	
	Wald test	LR test	Wald test	LR test	Wald test	LR test
	11.199	11.032	76.545	77.010	75.216	70.615
	(0.082)	(0.087)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 8	9.768	9.643	98.062	86.609	70.164	66.415
	(0.135)	(0.141)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 9	9.089	8.816	81.367	79.460	70.814	66.908
	(0.169)	(0.184)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 10	10.236	9.933	102.465	101.092	71.145	67.273
	(0.115)	(0.128)	(0.000)	(0.000)	(0.000)	(0.000)
Estimation 11	10.128	9.979	71.263	71.357	73.738	69.161
	(0.119)	(0.126)	(0.000)	(0.000)	(0.000)	(0.000)

Note: See Table 1 for definitions. P-values are in parentheses.
Source: Authors' estimations.

Table A6
Hausman test results

	Cropland		Forest		Grazing land	
	Spatial lag	Spatial Durbin	Spatial lag	Spatial Durbin	Spatial lag	Spatial Durbin
Estimation 1	10.563	29.682	2.509	6.590	37.161	32.530
	(0.103)	(0.002)	(0.867)	(0.831)	(0.000)	(0.001)
Estimation 2	10.974	19.867	2.902	2.768	30.524	40.493
	(0.140)	(0.099)	(0.894)	(0.999)	(0.000)	(0.000)
Estimation 3	12.184	25.846	0.892	9.710	2.571	92.699
	(0.095)	(0.018)	(0.996)	(0.717)	(0.922)	(0.000)
Estimation 4	6.763	31.509	0.781	5.154	32.840	25.993
	(0.454)	(0.003)	(0.998)	(0.972)	(0.000)	(0.017)
Estimation 5	11.401	26.824	1.659	5.498	65.069	22.492
	(0.122)	(0.013)	(0.976)	(0.963)	(0.000)	(0.048)
Estimation 6	20.215	31.267	0.208	9.086	12.096	29.012
	(0.005)	(0.003)	(1.000)	(0.766)	(0.097)	(0.007)
Estimation 7	244.164	28.641	4.500	7.149	34.241	99.378
	(0.000)	(0.007)	(0.721)	(0.894)	(0.000)	(0.000)
Estimation 8	10.888	28.253	0.775	17.078	48.611	14.287
	(0.144)	(0.008)	(0.998)	(0.196)	(0.000)	(0.354)
Estimation 9	11.236	28.357	4.021	8.633	30.423	21.929
	(0.129)	(0.008)	(0.777)	(0.800)	(0.000)	(0.056)
Estimation 10	10.174	30.083	0.800	11.397	47.006	13.090
	(0.179)	(0.005)	(0.997)	(0.578)	(0.000)	(0.441)
Estimation 11	30.464	27.641	0.006	8.117	337.934	28.852
	(0.000)	(0.010)	(1.000)	(0.836)	(0.000)	(0.007)

Note: See Table 1 for definitions. P-values are in parentheses.
Source: Authors' estimations.

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