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The Spatially Differentiated Trends Between Forest Pest Control Efficiency and Pest-induced Losses in China

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Abstract

China historically exhibits spatial differentiation from population distribution to ecological or economic development, and the forest pest control work is an epitome of this tendency. In recent times, global warming, man-made monoculture tree plantations, increasing human population density and intensified international trade aggravate forest pest outbreaks. Although Chinese government has complied with the internationally recommended practices, few stones remain unturned due to existing differential regional imbalance of forest pest distribution and control abilities. Evidence shows that the high-income provinces in the south have taken advantage of economic and technological superiority, resulting in the adoption of more efficient pest-control measures. To the contrary, in economically underdeveloped provinces of the northwest, a paucity of financial support has led to serious threats of pest damage that almost mirrored the demarcations of the Hu Huanyong Line. In this paper, we propose introducing public-private partnership (PPP) model into forest pest control and combining the national strategies to enact regional prevention measures in order to break the current spatially differentiated trends in China.

Key words: forest pest; control effeciency; pest-induced losses; spatially differentiated

1.Introduction

Chinese culture originated from traditional Yellow River civilization and enlarged to recent

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Yangtze River and the Pearl River deltas as they render rich suitable environment for human to aggregate and develop, generating regional economic imbalances[1]. In 1935, an accomplished geographer Hu Huanyong discovered the famous Chinese population density distribution line, internationally referred to as the Hu Line. It extends from Heilongjiang in the China's northeast to Yunnan in the south, dividing the country into southeastern and the northwestern halves. The southeastern half accounts for 36% of the country's territorial area but 96% of the population, while the northwestern half occupies the remaining 64% land area with only 4% of the country's populace[2]. Especially, after the reform and opening-up policy in 1978, the eastern coastal region developed rapidly that deepened the wealth gap, emblematic of the socioeconomic divide of historical China[3]. It turns out that the Hu Line reveals an important characteristic that is also reflective of the country's ecological conditions, economic development potentials, and other aspects[4]. In 2014, Premier Li Keqiang pointed to the Hu Line on the map and stated that China, as the multi-ethnic country with a vast territory, needs to look into methods to break the traditional demographic pattern in order to make people from underprivileged areas such as the central and western regions benefit from modernization[5].

To this end, the government put forward several policies such as poverty reduction, ecological construction and other supports to releasing the existing imbalance situation[6]. Previous analyses have revealed that distribution of forest pest provides a stereoscopic view of these spatial trends. While the outbreak was affected by the ecological characteristic and meteorological conditions, its control measures were mainly influenced by socio-economic factors and management policies[7-9]. In 2001, China State Council (CSC) approved the Six Key Forestry Programs (SKFPs). Most of the approved programs related to enrichment planting of trees, such as Natural Forest Conservation Program, the Grain for Green Program, and Fast-growing with High-yield Timber Plantation Basement Program, all of which contributed to the total plantation forest reaching 69.33 million hectares in 2016[11-12]. However, common limitations of the plantation forests include, among others, lower biodiversity, simple community structure, young-aged forest stands, and large-scale afforestation[13]. Monoculture tree plantations coupled with increasing pressures from global warming, international trade and burgeoning human population have triggered spatial distribution of forest pests that reached 12.11 million hectares, accounting for over 17% of forest plantations,

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threatening ecological safety of the entire region[14-17]. Forest pests are responsible for the destruction of more than 350 million ha of global forestland annually[18], damaging USD 70 billion worth of global goods and services[19]. It was estimated that the USA and Brazil alone are expected to lose more than USD 14 billion and USD 17.7 billion annually due to forest pest induced damages[20-21]. China is projected to face a similarly alarming situation, wherein, it might sustain ecological and economic losses to the tune of USD 16.94 billion that exceeds 10% of the country's total forestry output anually[22]. These findings have attracted global attention and called for an adoption of efficient measures for controlling pest outbreaks from destroying forests.

The strategies adopted for forest pest management has progressed through four stages from reliance on natural defense, chemical control, integrated management, to ecological prevention[23]. The available literature on pest control dating from around the early twentieth century to the 1940s focused on biological measures of pest control combined with advances in agriculture technology and artificial capture[24]. Around the 1970s, chemical control measures emerged and exhibited remarkable effectiveness[25], however, at the cost of severe environmental degradation[26] that urged FAO (1967) to submit its first integrated pest control report in an effort to lessen pesticide pollution and improve pest control measures[27]. By the mid-1990s, USA first established integrated pest management (IPM) funds for the experts to verify the effectiveness of IPM systems signaling the formal entry into the IPM direction [28]. At present, ecological prevention measures such as sustainable pest management, and forest health monitoring which include assessment of the pest-control system dynamics or pest impulse responses**,** have been introduced into IPM to boost the effectiveness in regulating pest population density during outbreaks[29-32]. This strategy also encourage farmers' cooperation and predictions from software-based models to implement effective forest pest management[33-35].

China followed the internationally approved management measures for fighting forest pest induced damage, and released the Forestry Pest Control Regulations, Major Exotic Forestry Pest Emergency Measures, and other relevant regulations to standardize forest pest management[36-37]. The State Forestry Pest Control Administration (SFPCA) has adopted several measures, such as, biochemical prevention by airplane spraying 4.15 million hectare of forest area annually[17], and a focus towards the "3S" (Remote Sensing, Geographical Information System, and Global Positioning

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System) technology to complete automatic diagnostic monitoring systems, meanwhile using an economic approach to calculate the losses incurred from pest damage on a five-year cycle for monitoring the effectiveness of forest pest control[22,38-41]. All of these measures demanded an investment in the excess of USD 561.2 million annually and steadily increasing[17]. Based on these, the SFPCA has approved a proposal aimed at improving pest-damage prediction accuracy by 90%, the rate of quarantining the quality of seeds in place of origin by 100%, and reducing the forest pest damage rate below 4 per thousand by 2020[42]. The administration is now under pressure to meet these targets, as regional economic-ecological imbalances affect forest pest distribution and control abilities.

There are more than 8,000 forest pest species, including 5,020 species of forest insects, 2,918 species of microbial pathogens, 160 species of rodents and lagomorphs, 145 hazardous plant species. and 300 species are considered the most serious threat to the Chinese forests[19, 43]. Varied climatic and spatial conditions with characteristic vegetation types in different regions of China lead to variations in the resident pest species among different provinces. Specifically, *Hyphantria cunea*, *Apriona cinerea*, and leaf insects destroy temperate broadleaf forests; *Bursaphelenchus xylophilus* (Scolytidae), capricorn beetles, and weevil pests are hazardous for the coniferous forests; *Holcocerus hippophaecolus* and *Orgyia ericae* Germar infest the extremely vulnerable western desert vegetation; and plateau pikas cause extensive damage to regenerated or young stands[44,45], resulting in each province facing different degrees of pest-induced forest loss and drawing our attention to study the pest outbreak situation, the resultant losses, and their control efficiency. A study as such could form a basis to understanding the current forest pest management situation in China.

In this paper, we compare the proportions of northwest and southeast respectively to analyze the differences and the causes, holding northwest part as the example and the following percentage representing the northwest part to the whole country that we could also easy get the southeastern situation. The forests of the northwest account for 39.21% of the total national forest area of which only 11.85% are forest plantations, meaning there are more natural forests in this region. Notwithstanding, half of the northwestern plantations are already invaded by forest pests resulting in economic losses totaling 24.51% and even higher ecological losses of 49.82%. The control pressure seems more optimistic in the northwest than the southeast, however, greater attention needs to be paid during management and investment planning and decision making since forest pest control average efficiency in the northwest is almost 10% lower than in southeast. This, combining with ecological and economic construction, would help break the existing spatial differential trends in forest pest control.

2.Materials and Methods

2.1.Literature Review.

We performed literature review on the economic aspects associated with pest management, starting from an international perspective, leading to China, using the Web of Science^{TM} database and a special string of keywords about pest control efficiency to identify the relevant papers. Next, we used the Web of Science's 'refine' function to restrict the search results to the relevant field, and it yielded 1,630 sources from 1997 to 2017. We analyzed each source manually to reject the irrelevant papers, and retained only those containing information regarding pest control. Finally, a total of 136 papers were selected. Then, we used the same method to identify literature from the Chinese National Knowledge Infrastructure (CNKI) for determining the pest control situation in China and obtained 163 papers. Furthermore, we explored reports, chapters, and related books that provided the initial estimates of forest pest control situation in China and elsewhere, and visited the website of SFPCA or consulted with the staff for detailed knowledge on pest control. We extended our quest beyond forest pests to include instances of "natural disasters," "Hu Line," and "pest outbreak affecting factors" to ensure a more thorough analysis.

2.2.Losses Incurred from Forest Damage by Pests.

These losses consist of economic loss (EL) and ecological service loss (ESL). EL was calculated as: EL =Ld+La+Lq+Lo +Lp, where, Ld represents loss from stumpage death, La represents stumpage volume growth losses, Lq represents loss from stumpage quality reduction, Lo represents non-timber forest product losses, and Lp represents the costs incurred from prevention of pest-induced disasters. Details of the different components of the equation are provided below:

The loss from stumpage death (Ld) was calculated as $\mathrm{Ld} = \mathrm{Pz} \times (1 - \mathrm{Rr}) \times \mathrm{Tz}$, where Pz is the volume of the dead trees, Rr is the relative stumpage price of dead wood (%), Tz is the stumpage

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price.

The stumpage volume growth loss (La) was calculated as $\mathrm{La} = \mathrm{S} \times \mathrm{Ad} \times \mathrm{Ta}$, , where S is pest damaged forest area (ha), , Ad is the reduction in timber increment per ha and year, and Ta is the stumpage price.

The loss from stumpage quality reduction (Lq) was calculated as $\mathrm{Lq} = \mathrm{S} \times \mathrm{Rq} \times \mathrm{Tv}$, where S is the pest affected area (ha), Rq is the reduction in stumpage price due to pest damage, and Tv is the stumpage volume in the damaged forest.]

Non-timber forest product losses (Lo) were calculated as $\mathrm{Lo} = (\mathrm{P}_0\mathrm{Y}_0 - \mathrm{P}_1\mathrm{Y}_1) \times \mathrm{S}$, where Y_0 is the normal annual yield (kg/ha), Y_1 is the average yield (kg/ha) in damaged forests, S is the pest affected area (ha), and P_0 and $\mathrm{P}_1$are the price of non-timber products (per kg) produced in undamaged and damaged forests, respectively.

Ecological service loss (ESL) was derived by means of the biomass estimation method to evaluate the reductions in ecological services, and was calculated following the formula $\mathrm{Lu} = \mathrm{kv} \times \mathrm{V}_1$, where Lu is the forest ecological service loss value, kv is the estimated ecological service value of per unite(per m^{-3}), and V_1 is the volume loss (m^3). Based on these formulae, the SFCA have estimated the forest pest losses from 2006 to 2010 of each provinces, and then we showed the final result in figures 3-5 for further comparing, and the total loss is the sum of economic losses and the ecological losses[22,56].

2.3.Forest Pest Control Efficiency

The *Least Square Dummy Variable* (LSDV) and *Entropy Weight Method* (EWM) were used with the feasible factors Pest Area (PA), Control Area (CA), and Investment Funds (IF) extracted from the Forestry Statistical Yearbook for the period 2003-2016 of 31 provinces; the details of the factors are explained in Table 2 and we hypothesis the efficiency is the higher the better.

The LSDV model can be used to estimate parameters incomplete one-way fixed effect that we could get the regression results of 31 provinces by the panel data[66]. The formula was evolved from Cobb-Douglas production function with logarithmetics the data representing their elasticity and be expressed as follows, $\mathrm{lnIF}_j = \mathrm{Y}_{1\mathrm{j}}\mathrm{lnPA}_j + \mu_1$, $\mathrm{lnIF}_j = \mathrm{Y}_{2\mathrm{j}}\mathrm{lnCA}_j + \mu_2$, $\mathrm{lnCA}_j = \mathrm{Y}_{3\mathrm{j}}\mathrm{lnPA}_j + \mu_3$,

$\mathrm{lnCA}_j = \mathrm{Y}_{4\mathrm{j}}\mathrm{lnIF}_j + \mu_4$, $\mathrm{L.lnPA}_j = \mathrm{Y}_{5\mathrm{j}}\mathrm{lnIF}_j + \mu_5$, and $\mathrm{L.lnPA}_j = \mathrm{Y}_{6\mathrm{j}}\mathrm{lnCA}_j + \mu_6$. We utilized the software of Stata13.0 to obtain the Y_{ij}, where i refers to the six new indicators and j represents the 31 provinces of China. They were interpreted as when forest pest outbreak or control measures increased 1%, the corresponding changes of investment funds to analysis whether its timeliness and effective, and then, when pest outbreak and funds increased 1%, the control measures following floating degree, specifically, the control measure or financial payment might not easy make work immediately that we added the lag period factor expressed as $\mathrm{L.lnPA}_j$ to examine whether the control strategies could make the pest outbreak situation trend to decrease.

The EWM was used to evaluate the weight of Y_{ij} [67,68]. For the first four indicators ($\mathrm{Y}_{1\mathrm{j}}$ to $\mathrm{Y}_{4\mathrm{j}}$), we hypothesized positive to pest control efficiency that the value would be the larger the better and standard expression is $Y_{ij}' = \frac{Y_{ij}-\min(Y_{ij})}{\max(Y_{ij})-\min(Y_{ij})} + 1$, whereas for $\mathrm{Y}_{5\mathrm{j}}$, $\mathrm{Y}_{6\mathrm{j}}$ are negative with the smaller the better value expressed as $Y_{ij}' = \frac{\max(Y_{ij})-Y_{ij}}{\max(Y_{ij})-\min(Y_{ij})} + 1$. After we got the standardized Y_{ij}' to the calculate the weight as $p_{ij} = \frac{Y_{ij}'}{\sum_1^{31} Y_{ij}'}$ and entropy as $e_i = -\frac{1}{\ln 31} \times \sum_1^{31} p_{ij} \, . \, ln_{p_{ij}}$, then, we obtained the entropy weight as $W_i = \frac{1-e_i}{\sum_1^{31}(1-e_i)}$; finally the weight figures are $W_i = \{0.16911, 0.16948, 0.166922, 0.165147, 0.164668, 0.164669\}$, and the forest pest control efficiency expressed as $\mathrm{Y} = 0.169114{Y_{1j}}^* + 0.16948{Y_{2j}}^* + 0.166922{Y_{3j}}^* + 0.165147{Y_{4j}}^* - 0.164668{Y_{5j}}^* - 0.164669{Y_{6j}}^*$, we displayed the final efficiency of each province in figure 6.

2.4.Efficiency Affecting Factors.

We selected one cross-section data in 2016 of each province as an example to verify the significant effects of the affecting factors and calculated by the *Simultaneous Equation Model*, which is one three-stage least squares (3sls) combined two-stage least square method with the seemingly unrelated regression[68]. Detailed explanations of the formula and determinants are displayed as follows, all the data were also logarithmic for each province.

$$\begin{cases} Y_j = \alpha_0 + \alpha_1 lnX_{1j} + \alpha_2 lnX_{2j} + \alpha_3 lnX_{3j} + u_j \\ lnX_{1j} = \beta_0 + \beta_1 lnX_{4j} + \beta_2 lnX_{5j} + \beta_3 lnX_{6j} + \beta_4 lnX_{7j} + \beta_5 lnX_{8j} + t_j \\ lnX_{2j} = r_0 + r_1 lnX_{9j} + r_2 lnX_{10j} + r_3 lnX_{11j} + r_4 lnX_{12j} + r_5 lnX_{13j} + v_j \\ lnX_{3j} = s_0 + s_1 lnX_{14j} + s_2 lnX_{15j} + s_3 lnX_{16j} + s_4 lnX_{17j} + \varepsilon_j \end{cases}$$

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Table 1. The affecting factors of forest pest control efficiency and its explanation

Variable	**Description**	**Source**	**Unit**	**Abb.**
Control efficiency(Y_j)	Combined with pest infested area, control area, and area covered by control project funding	Estimated	%	Y_j
Pest area(X_1)	Contained mild, moderate, or severe pest outbreak area	FSY	Ha.	lnX_1
Control area（X_2）	Including chemical, biochemistry, artificial physical, biological, or others	FSY	Ha.	lnX_2
Investment funds(X_3)	Including central budget, local finance, and social investment fund	FSY	$	lnX_3
Forested area(X_4)	Combined with arbor of 0.2 canopy density, bamboo, shrubland, farmland forest network and all forest coverage by the side of village, road, water, or buildings.	FSY	Ha.	lnX_4
Accumulate temperature (X_5)	The accumulation temperature that daily mean temperature >10°C of one year	SMA	°C	lnX_5
Rainfall(X_6)	The rainfall volume	SMA	mm	lnX_6
Frozen area(X_7)	Including cryogenic or snow disaster area	NBS	Ha.	lnX_7
Drought area(X_8)	Drought disaster area	NBS	Ha.	lnX_8
Pollution-free control rate(X_9)	The percentage of biochemistry, artificial physical, biological or others ecological measures area to the total control area	FSY	%	lnX_9
Pesticide amount(X_{10})	Included microbial, biochemical, and chemical pesticides	SFPCA	kg	lnX_{10}
Control organizations(X_{11})	The forest pest control organizations, plant quarantine inspection and pest-monitoring stations, or social control organizations such as control companies, professional teams, or forestry hospitals	SFPCA	capita	lnX_{11}
Employee(X_{12})	Forest control institution members, quarantine inspectors, survey clerks and control workers in social service system	SFPCA	capita	lnX_{12}
Rural population(X_{13})	The rural population in China of each province	NBS	capita	lnX_{13}
GDP(X_{14})	Gross Domestic Product	NBS	CNY	lnX_{14}
Rural consumption (X_{15})	Chinese average rural consumption per capita of each province	NBS	CNY	lnX_{15}
Forestry investment(X_{16})	The total forestry investment funds of ecological projects, special business subsidy, infrastructure construction or others	FSY	CNY	lnX_{16}
Forestry output value(X_{17})	The total forestry output value of production systems.	FSY	CNY	lnX_{17}

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All the data were logged to represent elastic shown in the formulas and among the abbreviation (Abb.), FSY is Forestry Statistical Yearbook; SMA is State Meteorological Administration; NBS is National Bureau of Statistics.

All data were log transformed to represent elasticity and the CNY was converted to US $ using the exchange rate of 6.5 (1 US$ = 6.5 CNY).

3.Results and Discusiions

3.1.Forest pest damage and management situation between southwest and northeast.

Figure 1 displays the forest pest outbreak situation. It reveals that the pest damage is distributed across entire China. Xinjiang and Inner Mongolia had the higher incidences of pest outbreak and damage compared to other provinces. Figure 2 shows area under airplane control. Although it is a convenient to control the pest-induced damage by airplane, it would threaten the ecological and environmental balance by poisoning the fauna and the wildlife feeding them. Airplane control was used most frequently used measure in Shandong Province. In figure 3 and 4 show forest pest induced economic and ecological loss respectively and the combined total loss is shown in figure 5. The figures reveal that Xinjiang and Inner Mongolia incurred most damage both in terms of economy and ecology. Overall, forests of the southwest experienced most economic losses for its plentiful commercial forests, while forests of the northwest experienced more ecological losses resulting in a shrinkage of forest ecosystem services provided to nearby densely populated areas. Besides that, the total forest pest-induced loss in northwest was more serious than in the southwest except for Tibet. Due to the historical and climate factors, Tibet has more natural forest with lower pest damage. As for forest pest control efficiency, although most provinces are with lower efficiency in general, efficiency was highest in the southeast, especially in the coastal regions, than northeast expect Xinjiang. Comparing the forest pest induced losses with the control efficiency, we discovered that provinces that incurred higher losses were the ones with lower control efficiency such as Inner Mongolia, and this disparateness motivated us to inquire further on affecting factors.

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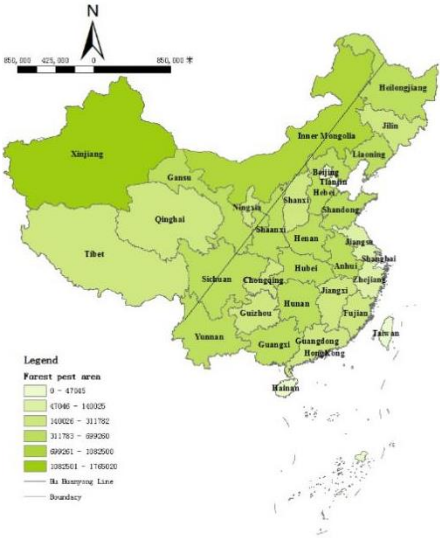

Figure 1. Forest pest area

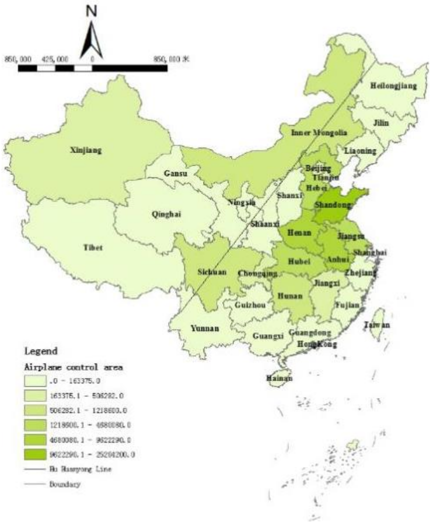

Figure 2. Airplane control area

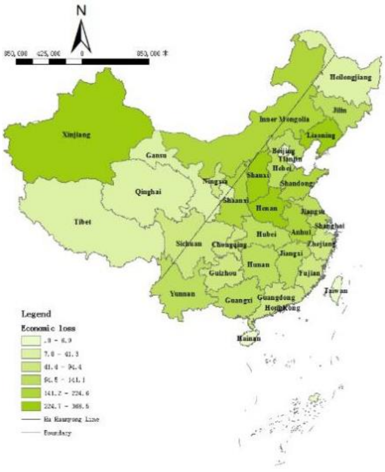

Figure 3. Economic loss

Figure 4. Ecological loss

Figure 5. Total loss

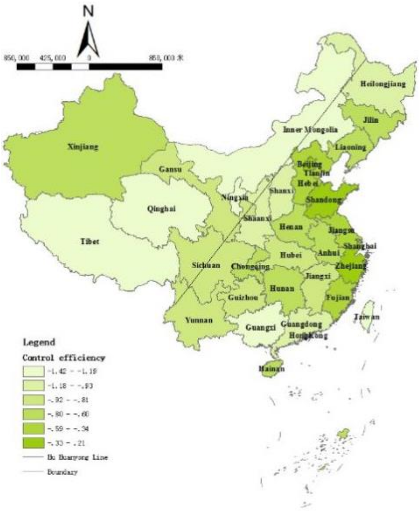

Figure 6. Forest pest control efficiency

The shades in the map from dark to light, represent the degrees from severe to gentle, the line in each map is our mentioned Hu Huanyong line. The northwestern part contains Xinjiang, Gansu, Tibet, Qinghai, Ningxia, Inner Mongolia and half of Sichuan, 10% of Yunnan provinces. And the southeastern part contains of Heilongjiang, Jilin, Liaoning, Hebei, Beijing, Tianjin, Shanxi, Shaanxi, Shandong, Henan, Hunan, Hubei, Chongqing, Jiangsu, Shanghai, Anhui, Zhejiang, Jiangxi, Guizhou , Guangdong, Fijian, Guangxi, Hainan, half of Sichuan and 90% of Yunnan provinces. The map in these figures were generated by GIS. Among of them, the unit of figure 1-2 is hectare, figure 3-5 is USA million dollar and the figure 6 is from -1.42% to 0.21% calculated by LDSV model, means when the control measures increase 1%, generating the following effect, as we could observed that the forest pest control efficiency was not really high of the whole country.

3.2.Factors affecting forest pest control efficiency.

We utilized the Simultaneous Equation Model (SEM) to analyze the affecting factors and their significant effects. The endogenous variables were Pest Area (PA) representing the natural characteristics of forest pests, Control Area (CA) representing the forest pest prevention and treatment effects and Investment Funds (IF) representing the forest control management processes, all of which were affected by exogenous variables such as forest characteristics, meteorological conditions, or socioeconomic well-being[46-50]. To be more precise, PA is impacted by forested area, accumulated temperatures, rainfall, frozen area, and drought area. For example, global warming is believed to reduce the frequency of cold spells and increase drought condition, both of which would trigger a forest pest outbreak[51]. We selected pollution-free control rate, the percentage of bio-control area to the total control area, pesticide amount, forest pest control organizations, relative employees, and rural population amount to evaluate the CA. Meanwhile, considering that the unbalanced labor force or financial conditions might influence the forest pest control efficiency via management decisions[52], we chose GDP, rural consumption, forest investment, and forestry output values to estimate IF. Finally, we regarded the impacted factors PA, CA, and IF as explanatory variables to regress the explained variable, forest pest control efficiency that we have calculated employing LSDV model shown in the Figure 6, details of which are explained in the methods section. Table 1 displays the regression results of forest pest control efficiency affecting factors.

As can be seen in Table 1, the model has passed the significance test of 1%, indicating that the SEM is considerably effective and all the endogenous variables passed the significance test. CA and IF emerge with conspicuously positive effects; when it increases by 1%, the control efficiency would increase by 0.406% and 0.326%, respectively. However, PA appears to have a negative effect, which decreases the efficiency by 0.415%. As for the exogenous variables, first with respect to PA, forested area, temperature, and rainfall all passed the significance test. Table 1 reveals that an increase of 1% in each of forest area and temperature would increase PA outbreak by 0.209% and 0.558%, respectively, whereas, 1% increase in rainfall would help reduce it by 0.513%. As for the CA factor, although none of the variables passed the significance test, the pollution-free control measures could play an important role under this condition, while the rural population is a negative variable that potentially burden the current protection strategies. Finally, in the IF regression results, the factors of GDP and rural consumption passed the significance test, and when they increased by 1%, IF increased by 1.389% and decreased by 2.121%, respectively.

Table 2. Factors affecting forest pest control efficiency

R^2=0.316	Pest area	Control area	Investment funds		Constant	
P=0.000	Coef. / Z-value	Coef. / Z -value	Coef. / Z -value		Coef. / T-value	
Control efficiency	-0.415***	0.406***	0. 237***		-2.674***(-4.57)	
	(-4.16)	(3.91)	(7.00)			
R^2=0.466	Forested area	Accumulate temperature	Rainfall	Frozen area	Drought area	constant
P=0.001						
Pest	0.209**	0. 548*	-0.513***	0.004	0.024	7.75***
area	(2.17)	(1.71)	(-2.27)	(0.1)	(0.44)	(3.7)
R^2=0.457	Pollution-free control rate	Pesticide amount	Control organizations	Employee	Rural population	constant
P=0.015						
Control area	1.017	0.129	0.06	0.185	-0.0870	4.858
	(1.34)	(1.55)	(0.24)	(0.73)	(-0.62)	(1.41)
R^2=0.42	GDP	Rural consumption	Forestry investment	Forestry output value	constant	
P=0.001						
Investment funds	1.389***	-2.121*	-0.130	-0.319	21.072***	
	(4.01)	(-1.86)	(-0.5)	(-1.18)	(2.18)	

Endogenous variables: Pest area, Control area, Investment funds

Exogenous variables: Forestland area, Accumulate temperature, Rainfall, Frozen area, Drought area, Pollution-free control rate, Pesticide amount, Control institutions, Employee, Rural population

GDP, Rural consumption, Forestry investment, Forestry output value

*All the values of the variables were logged except control efficiency to represent elastic, and the results were expressed as percentage. *, ** and *** are Significant at 10%,5% and 1% level, respectively.

3.3.Realistic significance of the affecting factors to forest pest outbreak.

We highlighted the typical pest *Bursaphelenchus xylophilus* as an example to verify the pest location regulation under the affecting factors. *B. xylophilus* is an invasive insect carried by *Monochamus alternatus* Hope (MAH) that has been highlighted as one of the most dangerous species by SFPCA and even a menaced to the world[53]. When MAH wounds the tree for nutrition, *B. xylophilus* drills into the resin and destroys the xylem[54]. Available literature suggest that it destroys over 0.33 million ha of pinewood causing economic losses in excess of USD 276.92 million annually[55]. As shown in Figure 7, the first appearance of *B. xylophilus* in the city of Nanjing overlaps with its intensification of international trade in 1982, and then rapidly expanded to the Yangtze River delta which supports a flourishing economy in China[56]. The rapid spread was aided by global warming and developing transportation that supplied a spawning environment for *B. xylophilus,* causing damage to spread consistently along the Hu Line expanding from the southeast to northwest between 1998 and 2015[57]. Although SFPCA has taken several measures to reduce the damage by constantly improving technology, there are historical spatial differences in natural and social-economic aspects leading to an expansion of original forest pest damage area elsewhere owing to the invasion by other more serious species that intensify the control difficulty. This remind us a need for further discussing the divisional strategies to improve the control efficiency, especially in determinants aspect.

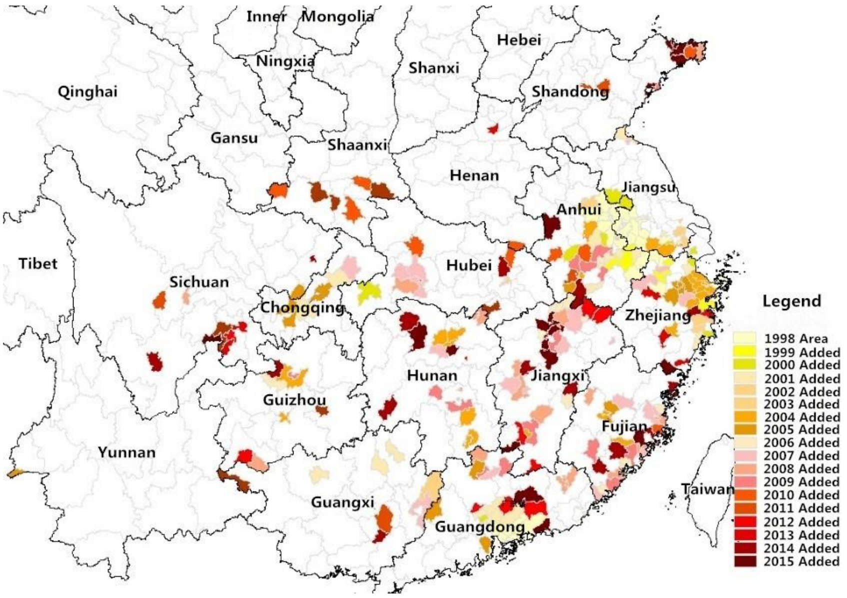

Figure 7. *Bursaphelenchus xylophilus* expansion tendency from 1998 to 2015 (Unit: county). This source has already been published in the website by SFA http://www.forestry.gov.cn/main/3600/content-941990.html and SFPCA http://www.forestpest.org/index.html.

4.Conclusions

Based on our findings, we concluded that the forests pests incurred great losses and their control efficiency appeared to differ geographically, showing distinct patterns in the northwest and southeast that almost resembles the demarcation of the Hu Line with higher losses in northwest with a corresponding lower control efficiency. The forest pest spread area, as a significant factor, restricted the control efficiency in the northwest as more SKFPs led to an increase of the forest coverage for ecological services and limited rainfall that enlarged the pest damage degree especially in forest pest ecological loss. However, as current control measures fall short of satisfying the province-specific protection demands with deficient economic development ability to acquire enough funding support, actual investment in the control measures is needed for the northwest. Furthermore, the forest pest control measures as the public goods executed by the government, the actions of rural population are generally counterproductive both to preventive measures and fund simulation which remind us a need for introducing Public-Private-Partnership (PPP) model into the control work by encouraging the community co-management integrated with market mechanism and specialized regional management strategies[58].

Combining the forest pest control measures with the national regionalization strategies such as

SKFPs would help achieve the ecological construction with more mixed plantation, and eliminate absolute poverty and lower the wealth gap by 2020[59]. In northwestern part, following the Great Western Development Project and the Belt and Road Initiative development process to improve the economic development[60,61] while improving the new collective forestry property tenure reforms and the Tripartite Rural Land Entitlement System as separating rural land ownership rights , contract rights and management rights to enhance the farmers' willingness to participate in the forest management by planting diverse and economically significant tree species should be a top priority in order to improve the livelihoods of people in the region, which could be further extended throughout the country[62,63]. Therefore, SFPCA exerted the synthetic adjustment responsibility to consider the spatial differential control degree, that could also match the ongoing poverty alleviation initiatives to encourage farmers participate in forest pest control activities by supplying the forest ranger posts, or purchasing forest insurance through eco-compensation[64,65]. Meanwhile, mobilizing the social forces in technology and investment funds can be a possible way to guide the forest pest control companies to becoming more professional by hiring competent pest control team, and through diversified investment channels to impel existing forest insurance schemes get more complete with both the risk aversion and financial profit increment functions. This would not not only lessen the burden upon SFPCA and improve its control efficiency, but also, to an extent, break the spatial differential trends of forest pest control innovation reform progress.

Data availability. The authors declare that all data supporting the analyses and findings of this study are available within the article and its Supplementary Information files.

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Cai Y. S. provided the data and modified the paper.

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