Forests and Floods: Empirical Evidence from The Republic of Korea's National Reforestation Program

By

MIN, Kyonggi

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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Professor Lee, Changkeun, Supervisor ____________________

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Abstract

This paper conducts the empirical analysis of the relationship between forest stock and flood damage based on the Republic of Korea's national reforestation program (1973-1987). Reconstructing the historical forest statistics of Korea Forest Service and expanding Seo's (2018) dataset, I capitalize on a growing stock by forest types to examine whether coniferous, deciduous and mixed forests reduced flood damage. From a fixed-effect analysis, my results show that not all types of forests reduce flood damage. I find that coniferous or deciduous forests did not have a mitigation effect on flood damage, whereas mixed forests did. These results may reflect to the lack of a forest management policy and a coniferous-oriented reforestation program in Korea. From the results, this paper suggests that even if reforestation was successful, it might not lessen flood damage if forest management is not appropriately initiated after reforestation. Furthermore, deciduous forests should be adequately planted when one expects afforestation to ease flood damage.

Keywords: Republic of Korea's national reforestation program, growing stock, flood damage, coniferous forests, deciduous forests, mixed forests, forest management policy, fixed-effect model

1. Introduction

Forests play an essential role in mitigating floods. Forests have a hydrological function that holds water during the flood season and discharges water during the dry season (KFRI, 2007). When it rains heavily, forests soak up excess rainwater, preventing runoffs and damage from flooding (EEA, 2015). Forests also serve to fix the soil, preventing hydrological damage caused by landslides (KFRI, 2005). However, in the Republic of Korea, forests were destroyed and degraded during the Korean War (1950–1953). The denuded forestland caused frequent floods and landslides, even leading to damage to agriculture. To reduce hydrological disasters, the Korean government initiated a national reforestation program (1973-1987). Under the national reforestation program, nearly 2 million [1]coniferous and [2]fast-growing trees were planted. It was a successful forest transition by planting mainly coniferous and fast-growing trees. It led to a dominant opinion that the successful reforestation program reduced flooding. Nevertheless, few empirical studies have confirmed whether reforestation program mitigate flood damage.

Seo (2018), one of the few empirical studies, examines the effect of Korean reforestation program on flood damage. She finds that the reforestation program lessened flood damage by exploiting [3]the growing stock of total forests. This paper extends her paper by considering the type of forest. While the reforestation program focused on planting coniferous forests as they grow fast, their ability to mitigate flood damage is known to be weaker than deciduous or mixed forest. My study contributes to the literature by estimating a causal relationship between the reforestation program and flood damage by investigating forest types.

[1] Coniferous trees are evergreen, usually with needle-shaped leaves such as pines. Deciduous trees are broad-leaved trees that have fallen leaves, such as maple trees. According to the Korea Forest Law, coniferous forests are forests where coniferous trees account for more than 75 percent. Deciduous forests are forests where deciduous account for more than 75% in the forest. Mixed forests are forests where coniferous or deciduous trees account for more than 25 percent and less than 75 percent in the forest.
[2] Korean pine (*Pinus koraiensis*), pitch pine (*Pinus rigida),* larch (*Larix kaempferi*), and black locust (*Robinia pseudoacacia*)
[3] Growing stock is the diameter at breast height (DBH) multiplied by the height of a tree. It is used as the primary variable to measure the quality and quantity of forests in forest science.

My study is further motivated by the historical fact that Korean Forest Service (KFS) did not manage the planted coniferous forests for a long time since the reforestation program in Korea. The lack of management policy has caused side effects on the planted coniferous forests (KFS, 2003), such as excessive tree density in the planted coniferous forests (Choi, 2011). It resulted in a significant decrease in the hydrological function of forests (Kim & Jung, 2006). It is questionable whether coniferous forests with degraded hydrological functions reduced flooding.

Therefore, this study hypothesizes that coniferous forests would not have affected flood damage if the lack of management policies lowered the quality of coniferous forests. According to forest science theory, deciduous forests have an excellent hydrological function than coniferous forests, and mixed forests have better flood control functions than pure coniferous forests. I conduct a fixed-effect panel analysis to examine whether deciduous and mixed forests diminished flood damage. My results show that deciduous and mixed forests reduced flood damage, while coniferous forests did not.

My findings add to the long debate whether the hydrological function of forests can alleviate floods during the last decade. Bradshaw et al. (2007) confirmed that by exploiting cross-country panel data for 56 developing countries from 1990 to 2000, the number of flood events was associated with deforestation. Tan-Soo et al. (2014) found that the conversion of inland tropical forests to oil palm and rubber plantations in Malaysia has increased the number of days flooded. Sant'Anna (2018) identified that the frequencies of floods and landslides were mitigated in districts with relatively high forest cover in Rio de Janeiro. In recent studies, Tembata et al. (2020) confirmed that coniferous trees did not reduce flooding occurrence, and deciduous and mixed forests reduced flooding occurrence. On the other hand, the study by Bradshaw et al. (2007) was questioned by Van Dijk et al. (2009) and Ferreira and Ghimire (2012). Van Dijk et al. (2009) reexamined the results of Bradshaw et al. (2007) and confirmed that the results were not significant after controlling population density. Ferreira et al. (2013) argued that socioeconomic and institutional variables might be more critical in floods than forest cover. My study suggest that the type of forestation can matter.

This study has another innovation regarding the measurement of forests. Previous studies inferred the relationship between forests and floods by examining the relationship between forest *cover* and floods. In contrast, this study explores the profound connection between forests *stock* and floods because forest stock reflects the quality of forest management.

Finally, this paper also contributes to the empirical literature of Korean socioeconomic development. While the Korean reforestation is considered one of the most important development programs conducted since the 1970s, there have been no empirical studies on Korean reforestation program other than Seo (2018). This paper expands her study and present new results on the Korean reforestation program.

The rest of this paper is structured into five sections. Sections 2 and 3 describe the data and empirical strategy used in the study. Sections 4 discuss the effect of the reforestation program by forest types on floods. Finally, Section 5 summarizes the findings and mentions the study's limitations.

2. Data

The data section first illustrates independent variables and the corresponding dataset. Secondly, the dependent variable and the related dataset are described. Lastly, other factors affecting flood damage and the associated dataset are shown.

There is no record of where the trees were planted at the city and county levels during the reforestation program. However, the reforestation program targeted bare mountains nationwide (KFRI, 2007). Therefore, this study constructs the data for all cities and counties.

2.1. Independent variables

This study expands the previous study (Seo, 2018) by including additional years in the dataset. Since Seo (2018) used forest data at the city, county, and district levels every five years from 1985 to 2005 from [4]Water Resources Management Information System (WAMIS), the actual period of reforestation (1973-1987) was not included in the analysis. Forest data for the reforestation period (1973-1987) was attained from [5]the Statistical Annual Yearbook by KFS from 1967 to 1981, [6]except 1975 and 1980. The statistical Yearbook contains forest cover and growing stock of forests at the city, county, and district levels by forest type: coniferous forests, deciduous forests, and mixed forests. However, this study utilized city and county as observation units because forest cover is tiny at the city, county, and district levels.

The Statistical Annual Yearbook by KFS has limitations on data use for the analysis. Firstly, the Statistical Annual Yearbook did not annually report to which cities and counties the forests under the jurisdiction of KFS belong. To be more specific, the Statistical Annual

[4] WAMIS compiled the Statistical Annual Report of Local Government from every five years 1985 to 2005 on the website.
[5] I manually digitized the Statistical Annual Yearbook for the analysis because it was a pdf file.
[6] KFS did not report the Statistical Annual Yearbook for 1975 and 1980.

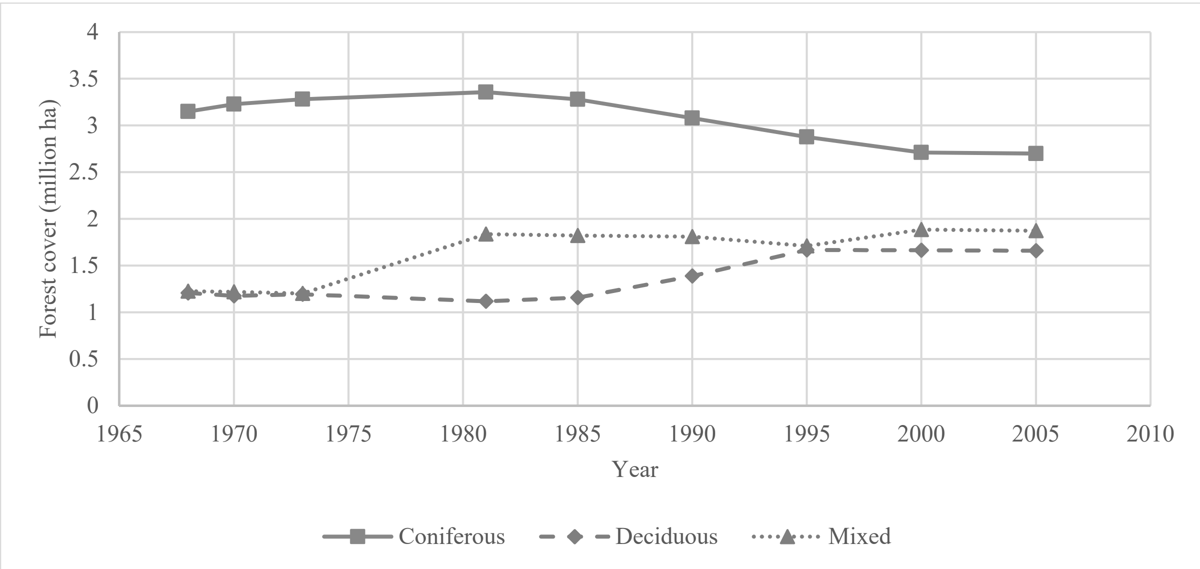
Yearbook was reported by dividing one forest in a city and county into [7]forests under the city's jurisdiction and forests under the jurisdiction of KFS. In order to calculate total forest cover and total growing stock of forests of city and county, it is necessary to add forests under the jurisdiction of city and county and forests under the jurisdiction of KFS. The information on which city and county the forests under the jurisdiction of KFS belonged was available in the statistical Yearbook for only 1967-1973, and 1981. Secondly, in the first stage, this study tried to exploit the Statistical Annual Yearbook by KFS for whole years. However, the Statistical Yearbook was reported only at the province level in the 1980s-1990s. For this reason, this study exploited the WAMIS dataset from 1985 to 2005. Therefore, this study reconstructed two datasets and appended the KFS Datasets for [8]1968, 1970, 1973, and 1981 to the existing WAMIS datasets for 1985-2005 at the city and county levels. Finally, this study expands four years from the previous study (Seo, 2018).

Following Seo (2018), this study exploits growing stock by forest type, other than forest cover that the previous studies used (Bradshaw et al., 2007; Tan-Soo et al., 2014; Sant'Anna, 2018; Tembata et al., 2020). Firstly, the growing stock has more implications than forest cover. Growing stock is calculated by diameter at breast height (DBH) multiplied by the height of a tree. The more trees are planted in a given area, the more incredible the growing stock of forests, and the greater the height and DBH of the tree, the more incredible the growing stock of forests. It implies that growing stock measures the growth of the planted forests. It is used as the primary variable to measure the quality and quantity of forests in forest science. Secondly, the effect of the reforestation program is more evident in growing stock than in forest cover. It is because coniferous forest cover continued to decrease due to economic development. Figure 1 shows the trend of forest cover by forest type. It was expected that coniferous forest cover had increased much during the reforestation program (1973-1987), but it has gradually decreased.

[7] Forests under the jurisdiction of cities and counties refer to local government forests and private forests.
[8] This study did not use 1967 as the first year because precipitation data omitted many cities and counties in 1967.

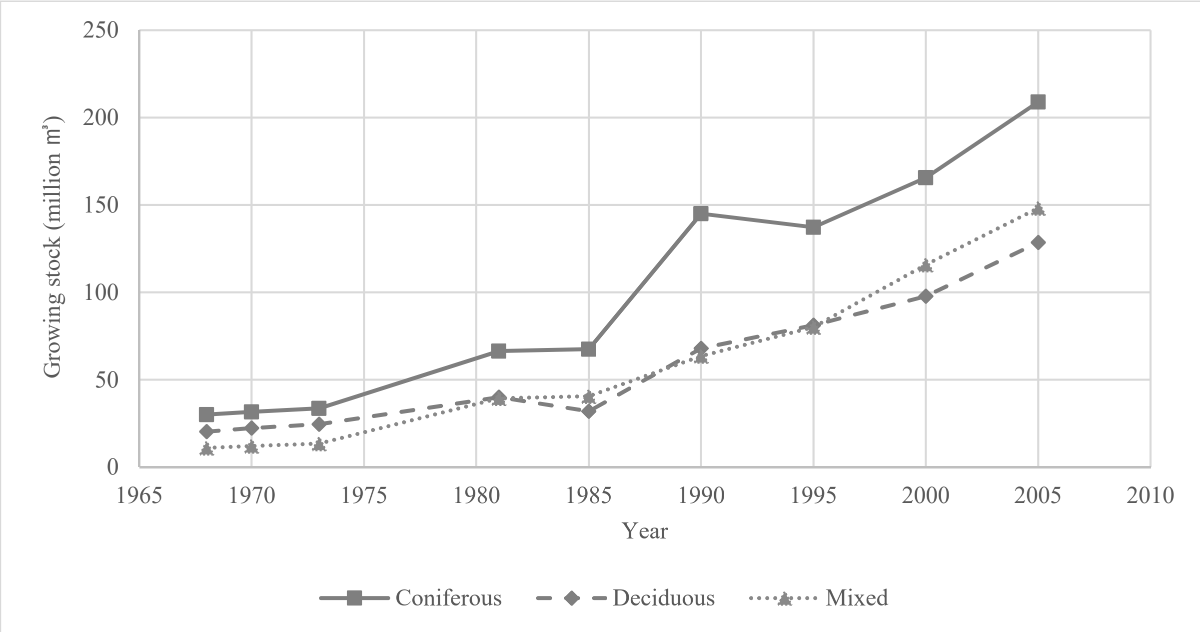
On the other hand, Figure 2 shows the trend of growing stock by forest type. In Figure 2, growing stock of coniferous forests has been significantly increased between years 1968 and 2005. This result was stemmed from the reforestation program (KFRI, 2006; KFS, 2015). Therefore, growing stock of forests are more appropriate to investigate the effect of the reforestation program on flood damage.

Figure 1. The Trend of Forest Cover by Forest Type



Notes: It exploited the KFS dataset from 1968 to 1981 and the WAMIS dataset every five years from1995 to 2005.

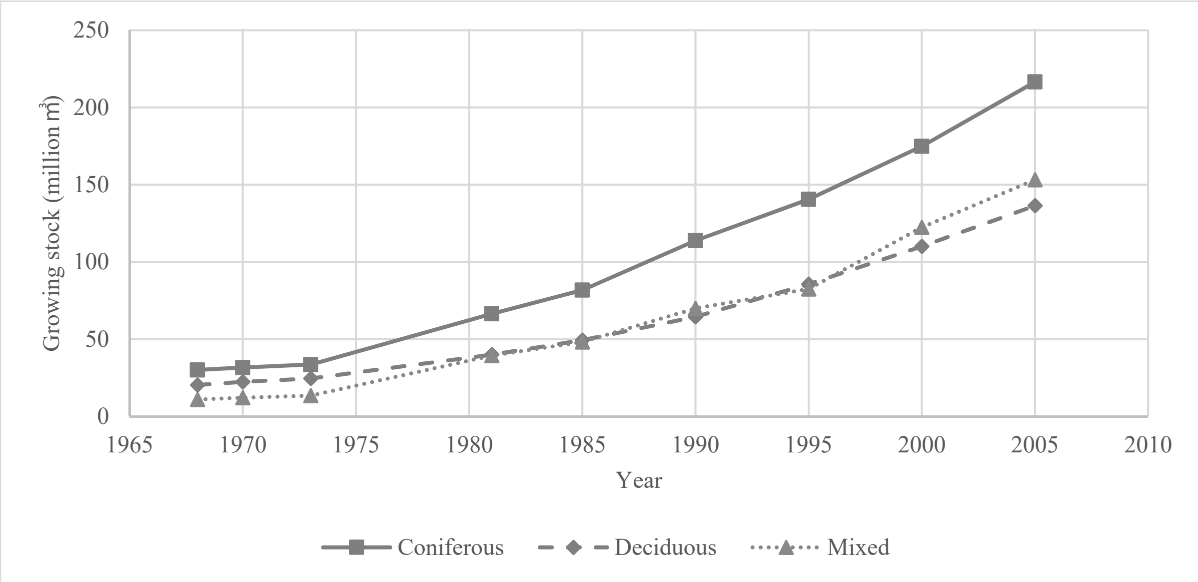
Figure 2. The Trend of Growing Stock by Forest Type



Notes**:** It exploited the KFS dataset from 1968 to 1981 and the WAMIS dataset every five years from1995 to 2005.

However, in Figure 2, the trend of the growing stock remained constant in 1985 and increased rapidly in 1990. WAMIS did not provide a specific explanation for this. To figure out, I newly constructed the dataset for growing stock by forest types exploiting only the Statistical Annual Yearbook by KFS. Figure 3 shows the trend of growing stock by forest types exploiting only the KFS dataset. Compared to Figure 3, Figure 2 shows that the WAMIS dataset underestimated the growing stock in 1985 and overestimated in 1990 than the KFS dataset. In addition, the WAMIS dataset was underestimated overall over the other years. Nevertheless, the trend is similar except for 1985 and 1990, which will be no problem using the data. Therefore, the years only 1985 and 1990 were excluded from the analysis.

Figure 3. The Trend of Growing Stock by Forest Type Using the KFS Dataset



Notes**:** It exploited the KFS dataset from 1968 to 1981 and the WAMIS dataset every five years from1995 to 2005.

2.2. Dependent variables

The flood-related data was obtained from the Statistical Annual Yearbook of Hydrological Disasters since 1967. The dataset reports damage variables caused by hydrological disasters at each city, county, and district levels. Damage variables in the dataset are nine variables: total flood damage (₩1,000), the number of evacuees and causality, flooded area (ha), farmland damage (₩1,000), crop damage (₩1,000), public facility damage (₩1,000), building damage (₩1,000), and other damage (₩1,000). Since the dataset is pdf and image files, I manually digitized pdf and image files from 1968, 1970, 1973, 1981, and every five years from 1995 to 2005, consistent with the years used in the forest dataset.

Although the dataset needs to be classified by causes because it reports hydrological damage from heavy rain, typhoons, and heavy snow, the dataset did not divide hydrological damage by causes until 1990. However, there are few problems using this dataset. Firstly, much of the typhoon damage is often caused by heavy rain. It is appropriate to include typhoons and heavy rain damage together. Secondly, most hydrological damages attribute to floods caused by heavy rains and typhoons. Heavy snow damage was tiny. Therefore, this study exploited this hydrological dataset as a flood damage dataset without classifying it by causes.

Based on Seo (2018), of nine variables, this study uses flooded area (ha), the number of evacuees, farmland damage (₩1,000), and crop damage (₩1,000) to confirm whether the reforestation program mitigate flood damage and agriculture damage. Farmland damage (₩1,000), and crop damage (₩1,000) were deflated by Producer Price Index (PPI) of agriculture products base year 2015.

2.3. Other factors of flood damage

There are other factors affecting flood damage. Based on the previous studies (Choi et al., 2004), this study considered the factors affecting flood damage by dividing them into two categories: 1) natural factors, 2) human geographical factors. Firstly, precipitation is the most critical one among natural factors. In particular, since most of the precipitation in Korea is concentrated in the summer season (June to August), annual flood damage in one region varies depending on the summer precipitation concentration. Therefore, this study used total annual precipitation and summer precipitation concentrations as natural factors.

Human and geographical factors include population and land permeability by land use in cities and counties. The population was included in the analysis because it is highly related to flooding (Van Dijk et al., 2009).

The monthly precipitation dataset by stations in the country was attained from Korea Meteorological Administration. This dataset was available since 1967. However, in 1967, no stations reported precipitation for all months, and only a few stations reported it for some months. For this reason, 1967's data were excluded from data generation. In order to generate data at the city and county levels using data by station, this study used a method of assigning the data of the nearest station to the precipitation of the relevant city and county.

Population-related datasets were acquired from Korean Statistical Information Service (KOSIS). However, the dataset was available for 1967, 1970, 1975, and every five years since 1980. For this reason, this study used linear interpolation for the population of intercensal years 1973 and 1981.

In this paper, the city and county were reconstructed based on 2016, reflecting the most recent change in administrative city and county. This study classified all metropolitan cities as city and county units for the analysis. This study excluded Seoul and Busan, the first and second-largest cities in Korea. These cities are likely to be well-equipped with disaster prevention infrastructure. The study also excluded island areas: Jeju island, Ulleung-do, and Baeng nyeong-do.

Furthermore, this study considered cities and counties in coastal areas vulnerable to floods and typhoons. There were 15 coastal regions vulnerable to flooding due to heavy rains and typhoons (Lee, 2016). Even if these regions are included in the analysis, the results were not changed. This study included these regions. Finally, I merged forest data, flood data, and precipitation and population-related data, including 1968, 1970, 1973, 1981, and every five years from 1995 to 2005, constructing panel data at the city and county levels.

Table 3 summarizes the data used in this paper. Dependent variables are flooded area (ha), the number of evacuees, farmland damage (₩1,000), and crop damage (₩1,000). Next, independent variables are the growing stock of forests by forest type: coniferous forests, deciduous forests, and mixed forests. Lastly, control variables are population, total annual precipitation, and summer rainfall concentration. In table 3, coniferous forests account for more than 40 percent of the total growing stock of forest and forest cover. Also, more than half of the annual precipitation is distributed in summer.

Table 1. Summary Statistics

Variable	Mean	SD	Min	Max	Obs.
Flood damage					
Flooded area (ha)	593	2043	0	49372	962
The number of evacuees	324	1536	0	30032	962
Farmland (₩1,000)	272779	1012119	0	15200000	962
Crops (₩1,000)	492723	1738841	0	32100000	962
Forest stock (㎥)					
Coniferous forest	666808	869498	539	6420309	962
Deciduous forest	409762	713242	0	6137244	962
Mixed forest	415727	710402	0	7129094	962
Natural factors					
Total annual precipitation (mm)	1209	272	558	1957	690
Summer rainfall concentration (%)	57	13	16	85	690
Human geographical factors					
Population	180391	268334	117648	2531280	962

Notes: Sample includes 1968, 1970, 1973, 1981, 1995, 2000, and 2005. The unit of observation is at the city and county levels. Farmland damage (₩1,000), and crop damage (₩1,000) were deflated by PPI of agriculture products base year 2015.

3. Empirical strategy

As in the preceding literature (Seo, 2018), this study adopts the following log-log fixed effect regression model to test my hypothesis that coniferous forests would not have affected flood damage if the lack of management policies degraded the quality of coniferous forests.

$$Log(Y_{it}) = \beta_0 + \beta_1 \log(Coniferous_{it}) + \beta_2 \log(Deciduous_{it}) + \beta_3 \log(Mixed_{it}) + \phi log X_{it} + \theta_i + \delta_t + \varepsilon_{it} \quad (1)$$

where the subscript i refers to city or county, and t, year. The dependent variable Y_{it} denotes flooded area (ha), the number of evacuees, farmland damage (₩1,000) and crop damage (₩1,000) in district i, in year t. $Coniferous_{it}$ is growing stock of coniferous forest in district i, in year t. It is an independent variable of the main interest because coniferous trees were mainly planted during the reforestation program. $Deciduous_{it}$ is growing stock of deciduous forest. $Mixed_{it}$ is growing stock of mixed forest. A vector of time-variant control variables X_{it} includes other observable explanatory variables which could affect flood damage: total annual precipitation, summer rainfall concentration, and population. θ_i captures unobserved city or county fixed effects: the distance to the nearest river. δ_t captures time fixed effect, and ε_{it} is an idiosyncratic error.

The coefficient β_1 of the main interest measures the effect of the growing stock of coniferous forests on flood damage. According to my hypothesis, it was expected that the coniferous forests had no mitigation effect on flood damage. If the sign is statistically not significant, coniferous forests had no mitigation effect. However, coniferous forests may have lessened flood damage. The sign is statistically significant negative if coniferous forests had the mitigation effect on floods.

The Coefficient β_2 measures the effect of the growing stock of deciduous forests on flood damage. According to forest science theory, deciduous forests have an excellent hydrological function. Therefore, it was expected that deciduous forests reduce flood damage. The sign would be statistically significantly negative if these trees dminished flood damage.

The Coefficient β_3 measures the effect of the growing stock of mixed forests on flood damage. According to forest science theory, mixed forests have better hydrological functions than pure coniferous forests. Therefore, mixed forests would have alleviated flood damage. If the sign is statistically significantly negative, mixed forests eased flood damage.

4. Result

Empirical results are presented in Table 2 and Table3. Table 2 shows the estimation results on flooded area (ha) in Equation (1). Columns differ across the inclusion of control variables. In Columns (1), no control variables are included. Column 2 contains human geographical factors: population. Column 3 includes natural factors: total annual precipitation and summer rainfall concentration. Column 4 includes all human geographical and natural factors.

Table 2. Effect of Growing Stock by Forest Types on Flooded Area

Log Flooded Area	(1)	(2)	(3)	(4)
Log Growing Stock of Conifer Forests	0.40*** (0.14)	0.38*** (0.15)	0.22 (0.18)	0.22 (0.19)
Log Growing Stock of Deciduous Forests	0.08 (0.11)	0.09 (0.12)	0.20 (0.13)	0.19 (0.14)
Log Growing Stock of Mixed Forests	-0.32*** (0.07)	-0.32*** (0.07)	-0.25** (0.10)	-0.25** (0.10)
Log Population		-0.17 (0.28)		0.05 (0.32)
Log Summer Rainfall Concentration			1.54** (0.70)	1.57** (0.71)
Log Total Annual Precipitation			5.66*** (0.66)	5.65*** (0.66)
Year Dummy	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Number of Regions	154	154	142	142
Number of Obs.	962	962	690	690

Notes: The unit of the flooded area is hectare. The unit of growing stock of forests is cubic meters. Standard error in the parentheses is clustered at the city and county. *, **, and *** indicate the 10%, 5%, and 1% significance level.

Table 3 reports the estimated results on the number of evacuees, farmland damage (₩1,000), and crops damage (₩1,000) in equation (1). Columns (1), (2), and (3) display the effect of growing stock by forest type on the number of evacuees, farmland damage (₩1,000), and crops damage (₩1,000) in Equation (1).

Table 3. Effect of Growing Stock by Forest Types on the Number of Evacuee and Agriculture Damage

	(1) Log Evacuees	(2) Log Farmland	(3) Log Crops
Log Growing Stock of Coniferous Forests	0.13	0.56	-0.68
	(0.12)	(0.34)	(0.44)
Log Growing Stock of Deciduous Forests	-0.10	-0.01	0.13
	(0.10)	(0.23)	(0.27)
Log Growing Stock of Mixed Forests	-0.14*	-0.60***	-0.26
	(0.07)	(0.22)	(0.26)
Log Population	0.42*	0.39	-0.29
	(0.23)	(0.46)	(0.54)
Log Summer Rainfall Concentration	1.09*	1.94	2.08
	(0.56)	(1.43)	(1.38)
Log Total Annual Precipitation	4.19***	10.64***	2.97**
	(0.50)	(1.15)	(1.18)
Year Dummy	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Number of Regions	142	142	142
Number of Obs.	690	690	690

Notes: Farmland damage (₩1,000) and crop damage (₩1,000) was deflated by PPI of agriculture products base year 2015. The unit of growing stock of forests is cubic meters. Standard error in the parentheses is clustered at the city and county. *, **, and *** indicate the 10%, 5%, and 1% significance level.

4.1. Why did not coniferous forests have a mitigation effect?

First of all, as shown in column (1) of table 2, When the growing stock of coniferous forests increased by 1%, holding other variables constant, flooded area (ha) increased by 0.40%. It is statistically significant at the one percent significance level. In column (2), the human geographical factors were included. When the growing stock of coniferous forests increased by 1%, holding other variables constant, flooded area (ha) increased by 0.38%. It is statistically significant at the one percent significance level. When the precipitation factors were included in column (3), growing stock of the coniferous forests are not statistically significant. Precipitation factors would be closely related to the flood because of the monsoon season in Korea. When all control variables were included in column (4), growing stock of the coniferous forests are not statistically significant. In columns (1), (2), and (3) of table 3, growing stock of the coniferous forests are not statistically significant. Overall, coniferous forests had no impact on flooded area (ha), the number of evacuees, farmland damage (₩1,000), and crop damage (₩1,000).

The results were consistent with my hypothesis. The results indicate that coniferous forests did not have the mitigation effect on flooded area, the number of evacuees, and flood damage to agriculture. The results would have attributed to the lack of forest management policy and the coniferous-oriented reforestation program.

Firstly, it is the lack of coniferous forest management policy after the success of the reforestation. The lack of management policy has caused side effects on the planted coniferous forests (KFS, 2003), leading to the high tree density (Choi, 2011). It downgraded the hydrological function of forests (Kim & Jung, 2006). The unmanaged forests with the decreased hydrological function of the forest can become vulnerable to floods, landslides, and droughts because of the increased evapotranspiration, interception of rainfall, and fallen leaves (Hong et al., 2010).

To be more specific, forest soil plays a significant role in the hydrological function of forests. In forest soil, the physical and chemical properties of the soil are developed by the decomposition of the deciduous layer (KFRI, 2002). Such forest soil has excellent rainwater infiltration and retention capacity when it rains (EEA, 2015). The rainwater infiltration capacity of forests is 2.5 times better than devastated areas and 20 times better than asphalt areas (KFRI, 2002). However, if forests are not managed, the fallen-leaved layer on the soil surface becomes thicker. The thickened fallen-leaved layer is not well decomposed. It prevents rainwater from infiltrating the soil and increasing the amount of surface runoff. The undecomposed fallen-leaved layer reduces the development of soil pores. It decreases the hydrological functions of forests. There are currently 2.3 million hectares of coniferous forests planted during the reforestation program, but the capacity to absorb and retain water lowered. If it rains 100mm, about 93mm outflow at once, increasing the risk of flooding (KFS, 2003). Therefore, the excessive tree density in coniferous forests would have prevented them from mitigating floods and instead made them vulnerable to floods.

Secondly, it would stem from the side effect of the coniferous-oriented reforestation policy. The planted coniferous trees would have provided an environment vulnerable to floods during the reforestation program. Korean reforestation program mainly planted coniferous and fast-growing trees to recover the devastating mountains quickly. [9]The planted coniferous trees were mainly pitch pine (*Pinus rigida*) and larch (*Larix kaempferi*). The type of these trees is representative of the shallow-rooted trees. If the density of these trees increases excessively, there is a high risk of being overturned by hydrological disasters such as typhoons and heavy rains (KFS, 2004). After the reforestation program, the planted coniferous forests had been

[9] Korean pine (*Pinus Koraiensis*) was also planted. Korean pines are deep-rooted trees but are vulnerable to landslides due to their weak capacity to fix the soil (Cha, 2016).

neglected after the reforestation program (KFS, 2003). It caused an excessive tree density in coniferous forests (Choi, 2011). This environment would have made these trees less hydrological and vulnerable to landslides during the monsoon season, increasing the likelihood of flooding. As a result, coniferous forests with shallow roots would not have had the effect of mitigating flood damage.

The trend of forest policy since the 2000s shows evidence for the above two reasons. Since the end of 1990, KFS has seriously recognized the side effects of the planted coniferous forests. As a result, KFS has changed the underlying policy from reforestation to management policy since the 2000s. For example, one forest management policy is a long-run forest management plan for the five major river basins since 2000. (KFS, 2000). The main goal of this policy is to improve the degraded hydrological function for flood prevention by thinning 134,747 ha of coniferous forests. By thinning, the policy also targets converting inferior coniferous forests into deciduous and mixed forests with excellent flood control. Therefore, given the goals of this policy, it supports my hypothesis that coniferous forests would not have affected flood damage if the lack of management policies degraded the quality of coniferous forests.

4.2. Why did not deciduous forests reduce flood damage?

As shown in column (1) of table 2, growing stock of the deciduous forests are not statistically significant. Even if control variables were contained in columns (2), (3), and (4), growing stock of the deciduous forests are not statistically significant. In addition, in columns (1), (2), and (3) of table 3, growing stock of the deciduous forests are not statistically significant. Overall, deciduous forests did not mitigate any flood-related damage variables.

According to forest science, deciduous forests have better hydrological functions than coniferous forests. Deciduous forests store 28.4 tons of rainwater per day in the soil during the flood season compared to inferior coniferous forests (KFS, 2003). On the other hand, coniferous forests have a slower rate of decomposing fallen leaves than deciduous forests because they are acidic (Koo, 2006). It degrades a forest soil's rainwater infiltration and retention capacity (Koo, 2006). According to a forest science experiment (KFRI, 2016), coniferous forests had an average annual outflow rate of 21.2% lower than broad-leaved forests because coniferous forests' soil cannot absorb rainwater well when it rains (Koo, 2006; KFRI, 2016). Eventually, coniferous forests cause runoff that sweeps the soil, further degrading the soil's function.

Based on the scientific evidence above, deciduous forests were expected to reduce flood damage. However, they did not lessen flood damage. It would have stemmed from a coniferous-oriented reforestation program. The coniferous-oriented reforestation program did not significantly help increase the growing stock of deciduous forests, while coniferous forests with relatively low flood control functions increased significantly. In Figure 2, the gap in growing stock between coniferous and deciduous forests was not significant in the early stages of the reforestation program. However, the gap widened even further after the reforestation policy. The growing stock of the deciduous forest is relatively tiny compared to coniferous forests. Compared to the difference between the growing stock of two species in 2005, coniferous trees increased by about 170 million cubic meters and deciduous trees by about 100 million cubic meters compared to 1968. Coniferous forests increased by more than 70 million cubic meters compared to deciduous forests. The two species show a significant difference in growing stock. Figure 2 also shows that deciduous forests have a minor proportion of the growing stock of the entire forest in 2005. Consequently, since the reforestation program have not primarily planted deciduous forests, deciduous forests would not have eased flood damage.

4.3. Why mixed forests alleviate flood damage?

In column (1) of table 2, When the growing stock of mixed forest increased by 1%, holding other variables constant, flooded area (ha) reduced by 0.32%. It is statistically significant at the one percent significance level. When the human geographical factor was included in column (2), the results were not different from column (1). When the precipitation variables were included in column (3), flooded area (ha) was reduced by 0.25%. It is statistically significant at the five percent significance level. When fully controlled in column (4), it had the same results as column (3). In column (1) of Table 3, when the growing stock of the mixed forest increased by 1%, holding other variables constant, the number of evacuees reduced by 0.14%. It is statistically significant at the ten percent significance level. In column (2), when the growing stock of the mixed forest increased by 1%, holding other variables constant, farmland damage (₩1,000) was reduced by 0.60%. It is statistically significant at the one percent significance level. However, in column (3), the effect on crop damage (₩1,000) are not statistically significant. Overall, mixed forests reduced flooded area (ha), the number of evacuees, and farmland damage (₩1,000).

In forest science, mixed forests have superior hydrological functions than simple forests. Unlike simple coniferous forests, mixed forests provide an environment where understory vegetation can inhabit well (Park & Kang, 2015). Since understory vegetation promotes the development of the soil pore by supplying organic matters such as plant roots (Park & Kang, 2015), The soil function of mixed forests is superior to that of simple coniferous forests. (Cha, 2016). In addition, the roots of understory vegetation play a role in fixing the soil, reducing the possibility of landslides (Youn et al., 2011). In the study on the frequency of landslides by forest type, coniferous forests were the most common, and mixed forests were the lowest (KFS, 2010).

These mixed forests not only have excellent hydrological functions but also prevent flood damage caused by landslides.

In this study, mixed forests alleviated flood damage, consistent with the scientific research results above. This result would have had a bearing on a significant increase in the growing stock of mixed forests. According to Figure 2, mixed forests increased by more than 140 million cubic meters in 2005 than 1968. The growing stock of the mixed forest was smaller than that in deciduous forests in the early stage of the reforestation program. However, it has surpassed deciduous forests since 1985. Mixed forests had more than 20 million cubic meters than deciduous forests in 2005. In conclusion, mixed forests would have diminished flood damage with the significant growth rate of growing stock.

5. Concluding Remarks

This paper conducted an empirical analysis of the relationship between forest stock and flood damage. In doing so, I differentiated the types of forests motivated by the knowledge of forest science. My results show that not all types of forests reduce flood damage. I find that coniferous or deciduous forests did not have a mitigation effect on flood damage, whereas mixed forests did. These results may reflect to the lack of a forest management policy and a coniferous-oriented reforestation program. Since the 1990s, the authority shifted the policy focus from planting more trees to manage the planted coniferous forests and continuously convert them into deciduous forests and mixed forests. These findings differentiate my study from Seo (2018), the only relevant previous study that used the total stock of growing forest and argued that it had positive effects on alleviating flood damage.

This paper expands the existing literature on the relationship between forests and floods. Existing studies (Bradshaw et al., 2007; Tan-Soo et al., 2014; Sant'Anna, 2018; Tembata et al.,

2020) focused on the variation of the forest cover, such as afforestation and deforestation, to identify the effect of the forests on floods. However, this study suggests that the type of forests and forest management can be critical in investigating the causal relationship between forests and floods by exploiting the growing stock other than forest cover.

My study also conveys policy implications. My results suggest that even if reforestation was successful, it might not lessen flood damage if forest management is not appropriately initiated after reforestation. If the reforestation policy mainly plants coniferous trees for economic profits, such as timbers, simple coniferous forests will not help alleviate floods. Therefore, deciduous forests should be adequately planted when one expects afforestation to ease flood damage. These lessons can be used for North Korea's reforestation program.

Closing the paper, I would like to mention the limitations of my paper. First, there might exist omitted variables bias. This study had to exclude the impermeable areas like concrete and asphalt and levee area due to the availability of data. Second, I found from data but did not explain why mixed forests increased more than deciduous forests. Deciduous trees were also planted as fast-growing trees, such as black locusts (*Robinia pseudoacacia*), while mixed forests would have naturally increased during the reforestation program. However, the increase in the growing stock of mixed forests was much more significant than that in deciduous forests. Finally, I did not upstream and downstream areas in the analysis. Forests in the upstream area may significantly affect the hydrological mechanism more than those in the downstream area. I hope that these issues to be addressed in the future study.

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