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ABSTRACT

The main objective of this study is to investigate whether and to what extent reforestation contributes on stabilization of water level in river, one of the expected benefits from forest, using both time series and panel data obtained from three rivers in Korea. The time series analysis using daily data collected from each river for the period from 1985 to 2005 show that the impacts of lagged water level and rainfall decrease as the volume of growing stock in adjacent forest increases. However, it is not certain whether that change is contribution of reforestation or contribution of unknown variables with trend. The estimations using panel data of six water level observatories and five rainfall observatories in the three rivers for the same period confirms that the changes in impacts of lagged water level and rainfall cannot be explained by a trend but my reforestation. According to simulations based on the estimation results, when it rains one hundred millimeter per day at time zero, the water level rises by 16.7% on that day, if the volume of growing stock is 1 million m^3. In contrast, the water level rises by 10.7%, if the volume of growing stock is 5 million m^3. Then, the effects of rainfall gradually vanish.

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I. Introduction

Forest provides essential services to human, which would include and not be limited to natural disaster prevention and provision of food, water, and raw materials. Forest is also known as a public good that provides significant positive externalities for human wellbeing at different scales. However, in the past, human activities led to significant deforestation, which was mainly for short-term economic profit. It is estimated that annual loss of forest from 2000 to 2010 is 5.2 million hectares (FAO, 2010), and there is urgent need to mobilize financial resources to recover the loss of forest.

Forest is known to regulate water from rainfall mainly through canopy interception and soil infiltration. The canopy interception refers to water that is retained by leafs of trees and evaporates into air. Besides the canopy interception, the rainfall can be delayed in reaching soil through stemflow, which refers to water that trickles along branches. The water that reached soil can either run off as overflow or absorb into the underground through soil infiltration.

In fact, a number of studies have been conducted on the positive effect produced from forest regarding its role in moderation of extreme weather events associated with rainfall. Hundecha and Bardossy (2004) demonstrated that intense afforestation reduces volume of runoff, which refers to water flows over the earth's surface due to storm or other weather conditions with intense rainfall. The reduced runoff would delay sudden increase in water level of river and thus prevent flood. Nisbet et al. (2004) showed that planting woods along a 2.2 km grassland reach of the River Cary in Somerset of U.K could delay the water velocity and produce flood prevention effect. Genwei (1999) found that reforestation in the upper Yangtze River Valley in China led to decrease in runoff. In Trinidad, Brookhuis and Hein (2016) showed that a non-linear relationship between catchment's forest cover and flood control. In addition, the study also estimated that the hydrological service of the forest cover is between 16 and 268 dollars per hectare per year.

According to UNISDR (2012), annual reported economic damages from natural disasters have shown an increasing trend as the amount increased from less than 100 billion dollars in 1980 to above 300 billion dollars in 2011. In fact, flooding has been known as one of the most damaging natural disasters in terms of economic loss (Berz, 2000). Considering the expected upward trend in economic damages caused by various factors including climate change and magnitude of damage caused by flood, additional research on forest regarding flood prevention is highly desirable as significant disagreements exist in views regarding investment in natural resources such as forest between group of developmentalists and that of conservationists. This issue is especially important for developing countries, which aim to boost their economic growth through aggressive development and are willing to sacrifice environment protection. In many cases, developing countries are more vulnerable to natural disasters and often have lower capacity to manage the damage caused by natural disasters.

Even though deforestation provokes worldwide concerns, there are countries that recognized the importance of forest in providing essential services for human wellbeing and succeeded at reforestation. South Korea is one of the successful countries which initiated nationwide reforestation projects in 1970s and accomplished significant reforestation. Due to the effort on the reforestation, according to the South Korean government, South Korea's volume of growing stock of forest, which is a statistic that represents forest inventory, increased from approximately 69 million m^3 in 1970 to 800 million m^3 in 2010. (Korea Forest Service).

Despite the apparent success of the reforestation, however, some still question whether reforestation is worthy of heavy investment from public fund raised by tax, and there is high demand for scientific analysis on the impact of reforestation.

In fact, there have been only few case studies to date that explore the benefits of reforestation in Korea. Against the background, the main objective of this study is to conduct empirical studies and test impact of reforestation on stabilization of water level in river, one of the expected benefits from forest, using both time series and panel data in order to draw economic implications regarding investment in reforestation.

In particular, this research paper collects rainfall and water level data of three Korean rivers, and examined whether and to what extent the impacts of rainfall on water level declines as the volume of growing stock of adjacent forest grows.

The following section describes the areas and rivers explored in this research. In section 3, the data used in the research will be discussed. The estimation equations employed in the research and the estimation results using time series and panel data are presented in section 4. Finally, the conclusion will be presented section 5.

II. Areas and Rivers explored

Since the present research aims at investigating whether and to what extent the impact of rainfall on the water level of a river changes as the volume of growing stock of forest increases, the areas in which factors other than forest might alter the effects of rainfall on water level are excluded. Such factors include existence of a dam and major constructions to widen or deepen a river. Adding on that, the data availability was also considered. Because rainfall is expected to affect water level of a river without a significant time delay, both daily and hourly data are necessary for this kind of research. In addition, the data of the volume of growing stock of forest must be available for a long time span. Finally, the existence of flood damage reports was also considered.

After extensive review, the research finally selected three rivers which include the HyeongSan River (HS River), the ManGyeong River (MG River), and the HongCheon River (HC River) in Korea.[1] For the three rivers, the volume of growing stock of forest in the watershed areas is reported every five year from 1985 to 2005. Besides, hourly and daily data of water level and rainfall are available for most periods from 1985 to 2014. However, mainly due to the lack of measurement infrastructure before 2000s, there are substantial amount of missing values especially in the hourly data. Since daily data have much smaller amount of missing values than hourly data, the research mainly use daily data for time series and panel analysis. Empirical research results using hourly data are reported in the Appendix as supplementary evidence.

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[1] Because it is not inevitably necessary to use the genuine local names of the rivers and observatories for the understanding of the paper, the paper will use an abbreviated name once a genuine full name is stated. An abbreviated name will be in a parenthesis following the genuine name when the latter is mentioned. Table 1 lists abbreviated names with their full names.

The water level and rainfall data used are official data announced by Ministry of Land, Infrastructure and Transport of Korea. The data for the HS River, the MG River and the HC River are provided by Nakdong River Flood Control Office, Geum River Flood Control Office, and Han River Flood Control Office, respectively. All the flood control offices are subsidiary organizations of Ministry of Land, Infrastructure and Transport of Korea.

<Insert Figure 1>

Figure 1 illustrates the location of the watershed area of the three rivers in South Korea. Figures 2 through 4 illustrate the water level and rainfall observatories in each river. This research analyzed the data of four water level observatories of the HS River, including MO (MO), AnGang (AG), BuJo (BJ), and PoHang (PH), and those of two rainfall observatories, including GyeongJu (GJ) and GiGye (GG). The HS River flows through the city of GyeongJu and the city of PoHang in the Province of GyeongSanBuk-do and flows into the East Sea. The basin length, which is the length from the mouth to the farthest point of the river, is 57.8 kilometers.

For the MG River, two water level observatories, including DaeCheon (DC) and DongJisan (DJ), and two rainfall observatories, including GoSan (GS) and ImPi (IP), were analyzed. The MG River flows through the city of WanJu and the city of IkSan in the Province of JeollaBuk-do and flows into the Yellow See. Its basin length is 74.8 kilometers.

For the HC River, two water level observatories, including BanGok (BG) and HongCheon (HC), and three rainfall observatories, including BanGok (BG), HongCheon Agricultural High School (HA) and NaeChon (NC) were analyzed. The HC River flows through the city of HongCheon in the Province of GangWon-do and joins the Han River, which flows through Seoul, the capital city of Korea and finally flows westward into the Yellow Sea. The basin length of the HC River is 108.5 kilometers.

<Insert Figures 2, 3 and 4>

Among the eight water level observatories mentioned above, PH in the HS River and DJ in the MG River are located near the river mouth and the sea. Therefore, the dynamics of the sea will affect the water level significantly, obscuring the effect of rainfall or reforestation. Accordingly, the two observatories are excluded in the analysis.

Figures 5-1 through 7-1 show rainfall and water level in each river, while figures 5-2 through 7-2 show water level and flood damage. Even though the flood damage data illustrated in those figures are yearly reports, because flood damages the watershed area of a river only between May and September in Korea, the rainfalls and water levels in the figures are average values of the five months from May and September. The unit of rainfall is millimeter per day for daily data and millimeter per hour for hourly data, and the unit of water level is meter above mean sea level. The flood damage is measured in one billion Korean won that is approximately equal to one million US dollar.

<Insert Figures 5-1 through 7-2>

As we can conjecture, a positive relation between rainfall and water level is observed in Figures 5-1 through 7-1. In addition, a positive relation between water level and flood damage is visually detected in Figures 5-2 through 7-2. Of interest is that a few episodes imply that flood damage is more closely related to water level than rainfall. For example, in Figure 5-1 GG rainfall observatory in the HS River watershed area reports more rainfall in 2006 than 2003, but the water level at the near-by AG water level observatory is higher in 2003. In Figure 5-2, that area reports more flood damage in 2003, when not the rainfall but the water level had a higher value than in 2006. In Figure 7-1, the Hongchen River had more rainfall in 1992 than in 1990, but the water was higher in 1990. Just like the previous example in the HS River, the HC River watershed area had more flood damage in 1990.

This finding is confirmed when flood damage is regressed both on rainfall and water level. Table 1 reports the estimation results of the following equation:

$$Y_{i,t} = \alpha_0 + \alpha_1 \log(RF_{i,t}) + \alpha_2 \log(WL_{i,t}) + \varepsilon_{i,t} \qquad \text{-------(1)}$$

where $Y_{i,t}$ is flood damage, $RF_{i,t}$ is rainfall, $WL_{i,t}$ is water level, and log is natural logarithm. The panel illustrated in Figures 5-1 through 7-2 are used for the estimation, and the equation is estimated by a fixed effect model. Table 1 reports the estimation results. When the two explanatory variables are included in the equation, the coefficient of rainfall is not significant even at the 10% significance level, while the coefficient of water level is significant at the 5% significance level. Moreover, the R^2 and the adjusted R^2 values indicate that water level explains more parts of the variability of flood damage than rain fall.

The visual hints from Figures 5-1 through 7-2 and the reports in Table 1 imply that stabilization of water level should be an important factor to reduce damage caused by flood. The current scientific technology cannot control rainfall. By preventing a river from flooding even in the case of a heavy rain, however, it will be possible to reduce the damage caused by heavy rain. If the water level is better controlled as the volume of growing stock of forest, it will be considered as a positive by-product of reforestation.

Meanwhile, Figures 8 through 10 show the volume of growing stock of forest in each watershed area of the three rivers. The lines in the figures are log values of the volumes, therefore their slopes represent the growth rate of the volume. As seen from Figures 8, the volume in the HS River watershed area was only 1.2 million m^3 in 1985, but increased to 5.3 million m^3 in 2005. It grew relatively fast between 1985 and 1990 and between 1995 and 2000. As a result, the volume reached more than 4 million m^3 in 2000.

<Insert Figures 8, 9 and 10>

The volume of growing stock in the MK River watershed area was 1.4 million m^3 in 1985, slightly higher than that in the HS River watershed area. However, since the volume grew more slowly than in the HS River area, it was only 3.2 million m^3 when that in the HS River area reached more than 4 million m^3. Different from the volume in the HS River area whose growth slowed down from 2000, the volume in the MK River area grew relatively fast between 2000 and 2005. Even so, it increased up to only 4.8 million m^3 in 2005.

Different from the two watershed areas mentioned before, the volume of growing stock in the HC River watershed area increased very rapidly between 1985 and 1990. It increased up to 4.9 million m^3 as early as 1990, which is the level the previous two areas reached in around 2005. This rapid growth of the volume in an early stage might be explained by that the HC River flows through mountainous areas. The growth rate of the volume in the HC River area slowed down from 1995, but the volume was 12 m^3 in 2005, more than two times of the previous two areas.

III. Data

For empirical estimations and tests, the daily data of water level[2] and rainfall obtained from observatories of the three rivers involved in this research are used. The daily data are collected for the period from January 1, 1985 to December 31, 2014. The measurement unit of water level is one meter, and that of rainfall is one millimeter per day.[3]

Regarding the daily data collected, it should be noted that water level data can differ according to the gage zero used. A gage zero is an arbitrary point, which is normally set below water surface of a river at the driest season. The water level above the gage zero is called a river stage and in many cases, water level observatories report only the data of river stage. Each gage zero has an elevation level above mean sea level, and the addition of a river stage and a gage zero is the water level of a river above mean sea level. Despite the convenience, since a gage zero can be changed due to change in shape of river or other reasons, river stage cannot be used for time series analysis unless gage zero has not been changes. For this reason, this study used the water level above mean sea level for consistency.

Because the water level data used in the research is the height of water above the mean sea level, they should show a consistency over time, in theory as far as there has not been a substantial structural change in the shape of the river. As previously mentioned, this research chose the three rivers because they are not significantly affected by dams or major constructions to widen or deepen the river. Even so, as Figures 11-1 through 11-6 shows, the water level data of some observatories show substantial structural changes.

<Insert Figures 11-1 through 11-6>

For example, water level at BG water level observatory illustrated in Figure 11-5 shows that water level was distinctively lower in 1996. For some reason, the gage zero of the observatory changed from 69.338 meter to 67. 338 meter, 2 meters down. However, it was raised back to 69.338 in 1997 and lowered down again back to 67.338 in 1998. The gage zero can be changed when there is significant artificial or natural change to the river beds in order to set it to an appropriate level under the lowest water level of a river (Rantz et al, 1982). The history of gage zero in each water level observatory is summarized in Table 2.

Accordingly, the water level may show structural changes due to measurement errors caused by using inappropriate gage zero. To deal with that problem, this paper uses dummy variables for the periods during which water level drops or jumps following changes in gage zero. The dummy variables used in the estimations in the following section are reported in Table 4.

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[2] A water level indicates a level above mean sea level.

[3] For the rainfall data, a datum indicates a height of the rain collected in a rain gage with the diameter of 20 cm.

As written before, the volume of growing stock of forest is measured every five years by Korea Forest Service. Therefore daily data are not available. However, different from economic and financial data, the volume is expected to grow quite steadily even if the growth rate may not be perfectly even. Based on that point, we obtained daily volume data by assuming a linear change in the volume. The first observation, the data of 1985, was used as Dec. 31, 1985 data. Accordingly, the last observation, 2005 data, was used as Dec. 31 2005 data. The volume data are available for only this period. Therefore, the time span of the research is limited to from December 31, 1985 to December 31, 2005. The measurement unit of the volume data is one million m^3. Because the measurement units of the variables are important when we interpret estimation results, they are summarized in Table 5.

IV. Time Series Data Analysis

1. Estimation equation

To determine whether reforestation has contributed to stabilization of water levels of the three rivers chosen, the following equation is estimated for each of the six water level observatories.

$$Y_t = \alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-1} F_t + \alpha_3 Y_{t-1} F_t L_t + \alpha_4 X_t + \alpha_5 X_t F_t + \sum_{j=0}^{m} \beta_j D_{j,t} + \varepsilon_t \qquad \text{----(2)}$$

In the equation (2), Y_t is the water level at a specific water level observatory and X_t is the amount of rainfall observed at the nearest rain-fall measuring spot. F_t is the volume of growing stock of the adjacent forest. L_t is a dummy variable whose value is one when rainfall is zero and is zero otherwise. $D_{j,t}$ is a period dummy variable to capture the effect of a structural shift in the water level possibly caused by a change in gage zero. As summarized in Table 4, the AG, the BJ and the DC observatories have one period dummy for each. The BG observatory has two period dummies because there were two distinctive changes in the gage zero in that observatory as previously explained.

Since the water level of a river should have a strongly positive relationship with its value of the previous day, α_1 is expected to be positive. In addition, since the amount of rainfall in one area will raise the water level of a river in the same area, α_4 is also expected to be positive. The coefficients, α_2, α_3, and α_5 of the interaction terms, $Y_{t-1}F_t$, $Y_{t-1}F_tL_t$, and X_tF_t will capture the impacts of the volume of growing stock of forest on water level. If Y_{t-1} increases by one meter, Y_t increases by $\alpha_1 + \alpha_2 F_t + \alpha_3 F_t$ when rainfall is zero, and by $\alpha_1 + \alpha_2 F_t$ when rainfall is not zero. If the forest has the function to stabilize water level, α_2 should be negative, but α_3 should be positive. If the rainfall, X_t, increases by 1 millimeter, water level, Y_t, increases by $\alpha_4 + \alpha_5 F_t$. If forest has the function to stabilize water level, α_5 should be negative.

2. Stationarity of the variables

When various unit root tests such as the Augmented Dickey Fuller test and the KPSS (Kwiatkowski et al., 1992) test are applied to the data used in Equation (1), there was little evidence of unit root for both the water level and the rainfall data. In contrast, the tests detected a unit root in the volume of growing stock data. Even so, we adopted a realistic assumption that the volume of growing stock of forest cannot increase indefinitely and converges to a certain point. Following the assumption, this research concludes that the volume data are also stationary. Therefore, conventional estimation methods for stationary variables will be adopted in the following sections.

3. Estimation results

Table 5 reports the estimation results of Equation (2) for each water level observatory. Based on preliminary estimation experiments, highly insignificant variables were dropped in the estimation equation of each observatory. Since the Breusch-Godfrey statistics indicates presence of serial correlation in every estimation equation, the standard errors were estimated by Newey-West method which produces standard errors robust to heterogeneity and serial correlation.

The coefficient of the one day lagged water level, α_1, is estimated to be between 0.782 at DC and 0.924 at MO. The estimated values of the coefficient are significantly positive. The impact of rainfall, α_4, is also estimated to be significantly positive as expected. The value ranges from 0.002 at BG to 0.008 at AG.

The coefficient of the interaction term between Y_{t-1} and F_t , α_2 , is estimated to be significantly negative without any exception, implying that forest has the function to reduce water level. In contrast, the coefficient of the same interaction term when rainfall is zero, α_3, is significantly positive only in the equation of AG. If α_3 has a positive value, forest reduces water level less when there is no rainfall. If the sum of α_2 and α_3 is positive, it can be interpreted that forest provides water to a river when there is no rain. However, even in the case of AG, the sum of α_2 and α_3 is negative. Those results imply that forest reduces water level more when there is rainfall in the AG area, and reduces water level in other areas regardless of whether there is rain or not.

Even though the findings from time series data seem to support the hypothesis that water level is better controlled as the volume of growing stock of forest increases, it should be noted that a trend can play a similar role to the volume of growing stock in equation (2). When the volume of growing stock, F_t , is replaced by a trend, all equations generate quite similar results reported in Table 6. The results of such estimation are reported in Table 7. However, the panel data analysis in the following section shows that the contribution of the volume of growing stock of forest cannot be replaced by a trend.

V. Panel Data Analysis

In this section, equation (2) is estimated using panel data comprised of the time series data of the six water level observatories examined in the previous section. Accordingly, there are six cross sections and the time span ranges from December 31, 1985 to December 31, 2005. The same variables used in section 4 are also used in this section except for the water level. Different from the rainfall and volume of growing stock data, the water level data show substantial disparity across the six rivers. For example, the mean water level of AG is 2.38 meters, while the mean water level of HC is 120.22 meters. This significant difference arises from the fact that the water levels are above mean sea level. Even though we include fixed effect dummies in the regression equation, this substantial disparity across cross-sections might affect the estimation results. Therefore, the logarithm values are used for water level in the panel data analysis. Accordingly, the estimation equation will be like the following:

$$LY_t = \alpha_0 + \alpha_1 LY_{t-1} + \alpha_2 LY_{t-1}F_t + \alpha_3 LY_{t-1}F_t L_t + \alpha_4 X_t + \alpha_5 X_t F_t + \sum_{j=0}^{m} \beta_j D_{j,t} + \varepsilon_t \qquad \text{-(3)}$$

where LY_t is the log value of Y_t. The definitions of all variables are the same as in Equation (2).

As previously mentioned, the variables included in the regression equation should be stationary. When the panel unit root test of Levin, Lin and Chu (2002) was performed, the null hypothesis of presence of unit root was strongly rejected for all the variables.

Table 7 reports the results for three different models: the simple OLS model (the model without fixed or random effects), the fixed effects model, and the random effects model. The simple OLS and the fixed effects model have two versions depending on the inclusion of period dummy variables. The random effect model cannot include the period dummy variables since the size of the cross-section, which is six in the present model, must be bigger than the number of explanatory variables in a random effects model.

The estimated coefficients have the same signs across the three models except for the coefficient for the interaction term between Y_{t-1} and F_t. It is negative and significant in fixed effects models, but it is positive and significant in other models contrary to our expectations. In tests which are not reported in Table 8, the F test with the fixed effect terms rejected the null hypothesis that the fixed effect terms are redundant. In addition, the Hausman test rejected the null hypothesis that there is no misspecification with the random effects model. Meanwhile, the period dummy variables in the fixed effects model are all significant. Accordingly, this research determines to use the estimation results of the fixed effects models with period dummies, which is Fixed Effects Model 2 in Table 7, to understand the effects of forest on water level.

The estimation results of Fixed Effects Model 2 show that an increase in rainfall raises the log value of water level, LY_t by (0.001825-0.000152* F_t) at time t. However, because LY_t includes LY_{t-1} as an explanatory variable, a change in rainfall increases LY_{t+1} through LY_t, and LY_{t+2} through LY_{t+1}, and so on. Since the coefficients of interaction terms of the volume and other variables such as water level and rainfall are significant, the impact of rainfall depends on the volume.

Of interest is that, different from the case of time series data analysis, the stabilizing effect of forest is not detected when the volume is replaced by the trend. As Table 9 shows, the coefficient of the interaction term between rainfall and the trend is not negative but positive, implying the effects of rainfall on water level increase as time passes by. This confirms that the stabilizing effects of forest are not caused by some unknown variable which can be replaced by the trend.

Figure 13 illustrates the simulated effects of rainfall on water level when the volume of growing stock is either one million m^3 or five million m^3. The graph shows the percentage changes of water level when the amount of rainfall is 100 millimeters per day at time 0. As Figure 8 shows, they are the volumes in the HS River watershed area in 1985 and 2005, respectively.

When it rains one hundred millimeter per day at time zero, the water level rises by 16.7% on that day, if the volume of growing stock is 1 million m^3.[4] In contrast, the water level rises by 10.7%, if the volume of growing stock is 5 million m^3. Then, the effects of rainfall gradually vanish as Figure 13 shows.

III. Summary and Conclusion

The main objective of this study is to conduct empirical studies to test impact of reforestation on stabilization of water level in three Korean rivers, the HS River, the MG River, and the HC River. The daily data used in the empirical studies are collected from three water level observatories and two rainfall observatories at the HS River, one water level observatory and one rainfall observatory at the MG River, and finally two water level observatories and two rainfall observatories at the HC River.

The three rivers were selected because they have not been affected by dams and/or major constructions to widen or deepen the rivers. In addition, data availability was also considered. The data for water level, rainfall, and volume of growing stock of forest are available in the three rivers for most of the time periods from 1985 to 2005.

In particular, this research paper regressed present water level on previous water level, present rainfall, and their interaction terms with the volume of growing stock. In the time series analysis of each water level observatory, the coefficients of previous water level and present rainfall were estimated to be positive and significant as expected. The interaction term between rainfall and volume of growing stock turned out to be insignificant. On the other hand, the interaction term between previous water level and volume turned out to be negative, implying that the water level is better controlled as the volume of growing stock increases. However, when the volume is replaced by a trend, similar estimation results were obtained except for one case, questioning the validity of the effects of reforestation on stabilizing water level.

Therefore, this research conducted estimations using panel data pooling the time series data collected from the three rivers. The estimated coefficient values are consistent with the hypothesis that reforestation stabilizes water level. Besides, when the volume of growing stock is replaced by a trend, the results are different from what were obtained from time series data analyses previously, confirming the effects of reforestation cannot be attributed to time trending effects.

Simulations employing estimated coefficient values show that reforestation reduces impacts of rain on water level substantially. Specifically, when it rains one hundred millimeter per day at time zero, the water level rises by 16.7% on that day, if the volume of growing stock is 1 million

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[4] The monthly average rainfall in August is around 9 millimeter per day. However, rainfall of one hundred millimeter per day is not rare in the summer time in Korea.

m^3. In contrast, the water level rises by 10.7%, if the volume of growing stock is 5 million m^3. Then, the effects of rainfall gradually vanish.

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Appendix

Estimations with Hourly Data

A1. Estimation Equation

As a supplementary work to the daily time series and panel data analysis, the hourly data were also analyzed. The findings from daily data imply that the impacts of rainfall on water level decline as the volume of growing stock of forest increases. To confirm that with hourly data, we split the hourly data into two sub-sample periods according to the level of reforestation. Considering that the volume of growing stock of river-adjacent forests in Korea sharply increased until 2000 and that the forest growth rate was moderated since then, the first time period is set to be from 1985 to 1999, and the second from 2000 to 2014. Then, we explored whether and to what extent the effects of precipitation level on water level become smaller in the second period.

Specifically, to determine whether reforestation contributed to stabilization of water levels of the three rivers chosen, the following equation is estimated.

$$Y_t = \alpha + \sum_{i=0}^{n} \beta_i X_{t-i} + \varepsilon_t \qquad \text{-------(A1)}$$

In Equation (A1), Y_t is the water level of a specific water level observatory and X_t is rainfall level observed at the nearest rain-fall measuring spot. Numerous preliminary estimation experiments showed that the estimated coefficients become very insignificant after a specific time lag in each river case, the length of time lag in X_t, or the size of *i*, is determined on the basis of the significance of estimated coefficients. For example, if coefficients become strongly insignificant from *t-j*, *n* is set to be *j-1*.

A2. Estimation Results

Tables A1 through A3 shows the brief summary of the statistics related to the estimations of equation (A1) for each river, which include number of observations, lags, and R-square values.

<Insert Tables A1, A2 and A3>

The HS River

As illustrated in Figures A1 to A4, the values of coefficients drop in the estimation with the data of the second period (2000-2014). In the case of MO and PH, the estimated coefficients of the second time period are smaller than those of the first period without even a single exception. In the case of AG, only the coefficient of t-4 is higher in the second period, and all the others are lower in the second period. In contrast, BJ shows a bit more complex results that the second period coefficients are higher from t-3 to t-13 and from t-37 to t-38. Even so, since the second period coefficients are lower in all other lags, it does not seem that the effects of rain fall on the water level remains the same or has increased in the second time period.

<Insert Figures A1 through A4>

The MG River

Figure A5 shows the estimated coefficient values of the equation of DC regressed on precipitation level of GS. Just like the results obtained from the data of the HS River, the coefficients of the second period are less volatile and smaller than those of the first period, implying the effects of rainfall moderated in the second period.

<Insert Figure A5>

The HC River

For this part, two water level observatories of the HC River were analyzed, BG and HC, and the nearest rainfall observatory to the two is HAHS. Since the estimation with the data of BG does not generate significant results at all, Figure A6 illustrates only the results obtained from HC.

Contrary to the previous two rivers, the regression using the data from HC and HAHS does not show that the coefficients become smaller in the second time period. As illustrated in Figure A6, the coefficients both in the first period and in the second period look very similar, implying there is not a structural break in the effects of rainfall on the water level in this area. This somewhat different result may be explained by the fact that the HC River is located in the province of Gangwon-do and flows through a mountainous area. Reforestation in Gangwon-do outpaced other areas in Korea, and the volume of growing stock grew fast from 1985 to 1990, but was moderated from 1995. In fact, the volume of growing stock reached over 4 million m^3 in 2000 in the forest of the HS River, and in 2005 in the forest of the MG River. In contrast, it reached over 4 million m^3 as early as 1990 in the forest of the HC River. Therefore, it may be a better idea to split the data around 1990 in the case of the HC River. However, due to a number of missing data in the period from 1985 to 1990, the estimation results for that specific time period are very poor and accordingly not informative.