Estimating economic benefits of urban conifers in terms of abatement of ultrafine dust (PM2.5)

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Abstract

Purpose – This study aimed to estimate the economic benefits of PM2.5 emission abatement by Red Pine, Pinus Koraiensis and Quercus, using a metering model analyzing the amount of PM2.5 absorption in Korea.

Design/methodology/approach – To estimate the economic effects of PM2.5 adsorptions by trees, the frequency of hospital visits resulting from respiratory and circulatory diseases was estimated using a Probit model based on the data from National Health and Nutrition Survey.

Findings – The results show that Quercus and Pinus Koraiensis absorb and eliminate the largest amount of PM2.5. Reducing 1 ton of PM2.5 emission through the planting of trees leads to lower incidences of respiratory and circulatory diseases equivalent to the amount of 95 million won. When the trees planted are 2-year-old Red Pine, Pinus Koraiensis and Quercus, the resulting economic benefits of the PM2.5 abatement would amount to 481 million won, 173 million won and 1,027 million won, respectively. If the trees are 80 years old, the economic benefits are estimated to be 73 billion won for Red Pine, 103 billion won for Pinus Koraiensis and 38 billion won for Quercus.

Research limitations/implications – One limitation of this study is that the weight of PM2.5 adsorbed by each leaf area entirely depended on the experimental results from a prior study and the values are likely to be different from those actually absorbed in natural surroundings. In addition, because of the lack of data from a domestic survey on the surface of leaf area or the reload flow rate of PM2.5, this study referred to data from foreign research. Unfortunately, this specific data may not reflect climatic and terrain characteristics specific to the target country. We used the annual wind speed to calculate the reload flow rate and elimination volume; however, the figures could be more accurate with hourly or daily climate variations. When estimating the health benefits of changes in PM2.5 emissions on respiratory and circulatory diseases, more segmented access to patients' hospital visits and hospital admissions are desirable. Finally, the study focused on the three major tree species of Korea, however, a more detailed study of PM2.5 reduction by various tree types is needed in the future.

Originality/value – This paper quantitatively assessed the amount of PM2.5 adsorption by each of the three tree species. Then, the economic benefits were calculated in terms of how much money would be saved on hospital visits thanks to the reduced PM2.5 levels and lower incidences of respiratory and circulatory system diseases. The net contribution of this study was to prove the trees' function of reducing PM2.5 as it relates to human health. We focused on the most common trees in Korea and compared them to provide new information on the species.

Keywords PM2.5, Conifers, Respiratory disease, Circulatory diseases, Health benefit

Paper type Research paper

1. Introduction

As fine dust is recognized as a major environmental pollutant, the seriousness of ultrafine dust and the resulting human health problems are increasingly important issues. Generally, air pollutants are categorized into either total suspended particles (TSPs) of 50 μm or less and fine dust particles of 10 μm or less, depending on the size of the particles. Fine dust can again be subdivided into tiny fine dust, which is less than 10 μm in diameter (PM10), and ultrafine dust, which is less than 2.5 μm in diameter (The Environment Ministry, 2016).

In particular, ultrafine dust consists of sulfate, nitrate (mass of atmospheric pollutants), carbon, soot, minerals, etc. and floats in the air as it is very light. If inhaled into the human body, it is known to cause respiratory diseases, lung cancer, cerebrovascular diseases, cardiovascular diseases and pain in the circulatory system (Abbey, 1995; Apte, 2015; Atkinson, 2014; Churg and Brauer, 1997; Fann et al., 2012; Guaita et al., 2011; Kloog, 2013; Lu, 2015; Lymburner, 2000; Nowak, 2013; Polichetti, 2009; Santibañez, 2013; Tecer, 2008; Wang, 2015; Xing et al., 2016). Ultrafine dust has an alveolar adsorption rate of 80–90%, much higher than the 50% of fine dust. It also has a wider surface area per weight and can adversely affect health if detrimental substances, including heavy metals, adhere to the surface of the particles and enter the human body (Shin, 2007).

Since 2015, the Air Quality Preservation Law in Korea has strengthened the standard for fine dust from the existing fine dust (PM10) to ultrafine dust (PM2.5), defining the daily average as 50 μg/m^3 and the annual average as 25 μg/m^3 (The Ministry of Environment Notice No. 2012–337). However, environmental standards are lax when compared to the World Health Organization (WHO) recommended standards (25 μg per day and 10 μg per year) or the national standards of the United States and Japan (35 μg per day and 15 μg per year, respectively). Notable in this regard is that the WHO International Agency for Research on Cancer (IARC) designated fine dust and ultrafine dust as first-class carcinogens in 2013 (WHO, 2013).

The occurrence of ultrafine dust with harmful substances is mainly attributable to the use of fossil fuels such as coal and oil, as well as emissions from factories and automobiles. In particular, the main sources of ultrafine dust emissions can be classified into moving pollutants on and off roads, combustion in the energy and manufacturing industries and scattering dust. Accordingly, the government is promoting policies and the development of related technology to reduce air pollution caused by automobile exhaust and thermal power plants (The Ministry of Environment, 2016). Among them, one eco-friendly means to abate air pollution in the future is allowing for trees to absorb ultrafine dust.

Trees have various public utility functions. They provide fresh air by releasing O_2 while absorbing air pollutants including greenhouse gases such as SO_2 and NO_2 through foliation during the photosynthesis process (Jo et al., 2003; Kim et al., 1992; Kim, 2013). Trees have shown an ability to remove PM2.5 in various experimental, metrical and physiological studies. For example, Jo and Ahn (2001a, b) calculated the quantity of air purified by coniferous trees in an ecosystem, while Jo (1999) reviewed trees absorbing atmospheric materials and heavy metals, purifying the air. Chen et al. (2015) identified that the amount and size of the fine and ultrafine dust accumulated on trees can vary depending on the tree species and its location. Mo et al. (2015) assessed fine dust deposited in the leaves and wax layers of 34 trees in Beijing, China. Zhang et al. (2017) found that urban trees have better fine dust absorbency than those in wetlands and have a stronger PM2.5 collection capacity than invasive aquatic species. Dzierżanowski et al. (2011) studied different kind of trees and plants of PM deposition on surfaces and trap in waxes and found significant difference on distribution of particle size fractions between the plant species and also between leaf surfaces and in waxes. In contrast to studies conducted abroad, however, only a few studies in Korea have quantitatively or qualitatively evaluated the adsorption or adsorption of PM2.5 by trees.

The most common tree species planted in cities and forests of Korea are Red Pine, Pinus Koraiensis and Quercus (Evergreen Oak). The trees are full of vitality and withstand air pollution. Maximizing trees' PM2.5 adsorption and air purification abilities in each age group is important in terms of the environmental value of plants. Moreover, this approach will contribute to our efforts to address climate change through the conservation and management of forest land. In addition, considering the public functions of trees, our efforts to expand forest land and plant more trees will eventually contribute to resolving climate change, not to mention improving air quality by lowering the PM2.5 level. Therefore, useful policy implications can be derived from measuring how much PM2.5 Red Pine, Pinus Koraiensis and Quercus can abate.

To identify the effect of these three tree species on PM2.5 emissions, we quantitatively assessed the amount of PM2.5 adsorption by each of the three tree species. Then, the health benefits were calculated in terms of how much money would be saved on hospital visits thanks to the reduced PM2.5 levels and lower incidences of respiratory and circulatory system diseases. The net contribution of this study was to prove the trees' function of reducing PM2.5 as it relates to human health. We focused on the most common trees in Korea and compared them to provide new information on the species.

The structure of this paper is as follows. The second section explains the method used to calculate the PM2.5 adsorption of the three trees and also the PM2.5 removal in cities and provinces, considering the PM2.5 reload flow rate of the trees as stated in the "2018 Forestry Statistics yearbook" published by the Korea Forest Service. The third section analyzes the effects of changes in PM2.5 emissions on respiratory and circulatory diseases with the aid of the "2014 National Health and Nutrition Survey" and a Probit model. The fourth section discusses economic benefits provided by the trees using estimates suggested in the second and third sections. The last section summarizes the analysis results to draw a conclusion and also provided limits of the study.

2. Estimation methods
About 1,000 species of trees inhabit Korea, where approximately 65% of the land is forested. Most of the trees are deciduous and Quercus is the most common tree followed by the Korean Red Pine. Coniferous trees are known to have higher PM2.5 collection capacities than those of deciduous trees (Zhang et al., 2017; Liang et al., 2016). Deciduous trees may have broader leaves that aid in PM2.5 adsorption. However, coniferous trees not only have many more leaves that can adsorb PM2.5 but they also are more effective in adsorbing pollutants in the air by slowing the wind velocity. Based on this, three main tree species planted in Korea were chosen in this research and they were the Pine and Pinus Koraiensis for coniferous species and Quercus for broadleaf species.

2.1 Leaf area and PM2.5 adsorption amount
The amount of PM2.5 adsorbed by trees can be calculated based on the Surface of Leaf Area (SLA). The total leaf area of each species was calculated using the estimated parameter of a "Tree Biomass Model and elements of an allometric growth table" drawn by the Korea Forest Research Institute of the Korea Forest Service. The mean of the SLA used in this study was cited from Schulze et al. (1994) and is shown in Table 1.

Eqn (1) is a biomass estimation model, in which y is the biomass of the stem; a, b and c are the parameters of the model; D is the diameter at breast height and H is the height of the tree. Table 2 shows the parameters and fitness index, which verifies reliability and error from the leaf allometric growth equation of a biomass model.

$$y = aD^b H^c \qquad (1)$$

The total leaf area was calculated by multiplying the weight of the leaves by the average of the SLA. The amount of PM2.5 accumulated on a leaf was cited from the results of an experiment with 25 species of trees planted in Beijing and Chongqing (Liang *et al.*, 2016; Nowak *et al.*, 2013, 2018) [1]. The research released by the Korea-China Air Quality Joint Research Team found similar PM2.5 elements, such as ammonium nitrate, ammonium sulfate and organic matter in Beijing and Seoul (NIER, 2020). The amount of PM2.5 accumulated on 2-year-old trees needed to be estimated through calculations as the Tree Stand Yield Table from the Korea Forest Service only has records for trees that are 10 years old or older. The tree planting initiatives by the government generally use 2-year-old, young trees due to cost and immunity reasons (Korea Forest Service, 2018). In order to evaluate immediate effects of the trees planted and compare them with gradual effects of the trees as they grow over time, it is necessary to calculate the PM2.5 absorption amount of the young trees. It is also useful to compare effects of P.M2.5 absorption among different tree types as they grow over times.

Although tree growth models are not in complete agreement with the real processes, they are usually described by using logistic models (Kumar *et al.*, 2014; Mohammadi Limaei *et al.*, 2017). The logistic growth model adopted in this study is a differential equation designed to be a simple model of population growth in ecology. The growth of trees follows a logistic growth pattern, which starts to grow slowly at its sprouting and then grows at a rapid rate once it reaches its growth phase. Therefore, a logistic model was used in this study to estimate the amount of leaves and PM2.5 accumulation. Following this period of rapid growth, the rate gradually slows. This pattern is termed the population growth curve and shows an *S* curve on the graph. Figure 1 shows the PM2.5 accumulations on Korean Red Pine, Pinus Koraiensis and Quercus with the logistic distribution.

2.2 PM2.5 reduction through tree planting by province

Unlike CO_2, PM2.5 is greatly affected by the weather, as most of the PM2.5 adsorbed on leaves is washed away via rain or floats in the air via wind. To reflect this, the reload flow rate of PM2.5 was calculated by applying the average annual wind speed for each city and province published by the Korean Meteorological Administration in 2014 to results from the experiment by Nowak *et al.* (2013) and finally removing the amount of adsorption from the calculation. During the rainy season, pollutants on the leaves are washed away via rain. The total precipitation storage capacity was calculated by 0.2 mm of rain collected on the leaves before falling to the ground (Nowak *et al.*, 2013). Because both the deciduous and

	Specific leaf area (m^2 kg^{-1})		
Vegetation type	Average	Standard error	N
Evergreen conifers	4.1	0.4	7
Temperate broadleaf	5.7	0.8	5

Table 1. Specific leaf area of coniferous and broadleaved tree

Tree species	a	b	c	Fitness index
Red Pine	0.233	1.840	−0.527	0.640
Pinus Koraiensis	0.026	2.471	−0.291	0.778
Quercus	0.108	1.630	−0.406	0.568

Table 2. Parameters and fitness index for tree species

Source(s): Korea Forest Service; Korea Forest Research Institute

Pinus Koraiensis

$m = 0.796\ln(n) - 0.6188$

y-axis: log(pm 2.5 Accumulation)
x-axis: Age

Korean Red Pine

$m = 0.5997\ln(n) - 0.0385$

y-axis: log(pm 2.5 Accumulation)
x-axis: Age

Quercus

$m = 0.4213\ln(n) + 0.4147$

y-axis: log(pm 2.5 Accumulation)
x-axis: Age
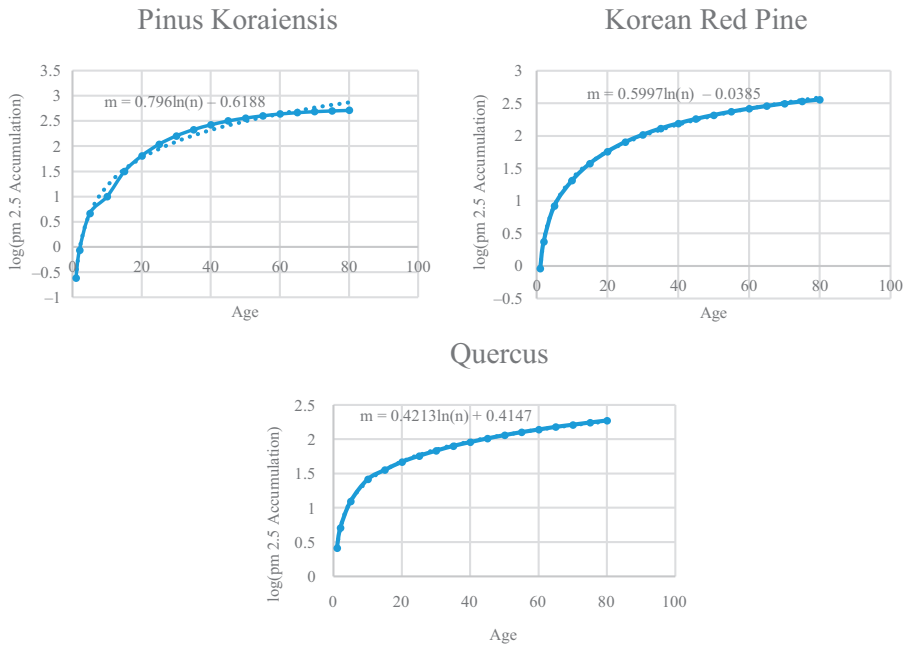
Figure 1.
PM2.5 accumulation on
trees by age

coniferous trees had a storage capacity of less than 1 mm by total precipitation, days when the precipitation exceeded 1 mm were counted as days when ultrafine dust was removed. The number of days was applied when calculating the amount of ultrafine dust removal per year.

To determine the total number of trees currently planted, this study referred to the 2018 Yearbook of Forestry Statistics from the Korea Forest Service. The total number of trees planted in each region in 2018 is 64,835,900 (Korea Forest Service, 2018), and this study assumed that the same number of Red Pinus, Pinus Koraiensis and Quercus is planted. Furthermore, it was assumed that the number of trees in each age group was equal across all age groups. Table 3 summarizes the reductions in the PM2.5 emissions estimated as previously described.

The results in Table 3 show that the Quercus removes the largest amount of PM2.5 among the 2-year-old trees, but the Red Pine shows the highest adsorption rate as its ages. In other words, for young trees, the PM2.5 reduction rate is fastest for the Red Pine, followed by Pinus Koraiensis and then Quercus, while for the older trees, the removal rate was fastest in Pinus Koraiensis, followed by Red Pine and Quercus.

3. Estimated results
Fine dust generated from industries and transportation on roads not only has a great impact on human health and the respiratory system but it can cause fatal diseases in the circulatory system. To estimate the economic effects of PM2.5 adsorptions by trees, the probability of developing respiratory and circulatory diseases because of PM2.5 was estimated. To explain the effects of PM2.5 reduction by trees health economically, we examined the relationship between PM2.5 and respiratory and circulatory diseases, both of which are closely related with fine dust, through a Probit model. Similar to Choe and Lee (2015), the frequency of hospital visits resulting from respiratory and circulatory diseases was estimated through a

Cities	Number of trees (1000 units)	Particle resuspension (%)	Rain days (>=1.0 mm)	PM2.5 reduction amount in red Pine(ton)						PM2.5 reduction amount in Pinus Koraiensis(ton)						PM2.5 reduction amount in Quercus(ton)					
				2 years old	10 years old	20 years old	40 years old	60 years old	80 years old	2 years old	10 years old	20 years old	40 years old	60 years old	80 years old	2 years old	10 years old	20 years old	40 years old	60 years old	80 years old
Seoul	140.2	3.9	66	0.00086	0.00744	0.02077	0.05631	0.09458	0.13103	0.00031	0.00361	0.0232	0.09578	0.15721	0.18525	0.00184	0.0094	0.01689	0.03282	0.05009	0.06779
Busan	1302.5	4.8	91	0.00188	0.01623	0.0453	0.12278	0.20625	0.28572	0.00068	0.00788	0.0506	0.20886	0.34281	0.40397	0.00401	0.0205	0.03683	0.07156	0.10922	0.14783
Daegu	75.9	3.075	76	0.00063	0.00546	0.01524	0.0413	0.06938	0.09611	0.00023	0.00265	0.01702	0.07026	0.11532	0.13589	0.00135	0.0069	0.01239	0.02407	0.03674	0.04973
Incheon	154.8	4.65	56	0.00092	0.00792	0.02209	0.05988	0.10058	0.13934	0.00033	0.00384	0.02467	0.10185	0.16718	0.197	0.00196	0.01	0.01796	0.0349	0.05326	0.07209
Gwangju	145.9	2.85	103	0.001	0.00865	0.02415	0.06545	0.10995	0.15232	0.00036	0.0042	0.02697	0.11134	0.18275	0.21536	0.00214	0.01093	0.01963	0.03815	0.05822	0.07881
Daejeon	80.7	2.25	83	0.00201	0.01737	0.04849	0.13141	0.22075	0.30581	0.00072	0.00843	0.05415	0.22355	0.36691	0.43237	0.00429	0.02195	0.03942	0.07659	0.1169	0.15822
Ulsan	188.6	3.3	87	0.00993	0.08575	0.2393	0.64857	1.08949	1.5093	0.00357	0.04161	0.26727	1.10329	1.81087	2.13392	0.02119	0.10831	0.19455	0.378	0.57693	0.78088
Gyeonggi	2676.7	2.25	68	0.2262	1.9543	5.45366	14.78117	24.82985	34.39761	0.08133	0.94832	6.09115	25.14449	41.27056	48.63288	0.48301	2.46853	4.43391	8.61472	13.1484	17.79653
Gangwon	3696.9	3	81	1.01646	8.7821	24.50726	66.4226	111.57863	154.57358	0.36547	4.2615	27.37198	112.99256	185.45876	218.54301	2.17052	11.09291	19.92479	38.71224	59.08535	79.97279
Chungbuk	31967.5	2.55	82	0.41163	3.55641	9.92449	26.89857	45.185	62.59628	0.148	1.72574	11.08459	45.75759	75.10358	88.50141	0.87898	4.4922	8.06877	15.67695	23.92727	32.38587
Chungnam	3305.7	2.4	86	0.82244	7.10579	19.82936	53.74396	90.28068	125.06882	0.29571	3.44807	22.14726	91.42472	150.05869	176.82788	1.75622	8.97551	16.12158	31.32291	47.80723	64.70771
Jeonbuk	10870.6	3.45	93	0.83944	7.25267	20.23924	54.85488	92.14684	127.65407	0.30182	3.51935	22.60506	93.31453	153.16049	180.48302	1.79252	9.16104	16.45483	31.97037	48.79544	66.04626
Jeonnam	4611.601	4.8	92	1.02285	8.83726	24.66119	66.83978	112.27942	155.54441	0.36777	4.28827	27.54389	113.70223	186.62357	219.91562	2.18415	11.16258	20.04994	38.95538	59.45645	80.47507
Gyeongbuk	3792.6	3.15	79	0.32866	2.83959	7.92413	21.47694	36.0776	49.9795	0.11817	1.37791	8.8504	36.53478	59.96585	70.66324	0.70181	3.58676	6.44244	12.51713	19.10453	25.85823
Gyeongnam	2392.2	2.4	83	0.3516	3.03775	8.47712	22.97574	38.59533	53.46739	0.12642	1.47406	9.46804	39.08441	64.15065	75.59458	0.75079	3.83707	6.89204	13.39066	20.43777	27.66279
Jeju	8858.7	4.35	99	0.00779	0.06727	0.18773	0.5088	0.85469	1.18403	0.0028	0.03264	0.20967	0.86552	1.42061	1.67404	0.01663	0.08497	0.15262	0.29654	0.45259	0.61259
Total	74261.1	53.175	1325	5.04428	43.58195	121.61951	329.62812	553.71901	767.08533	1.81369	21.1481	135.83592	560.73577	920.35582	1084.53943	10.77141	55.04957	98.87859	192.11297	293.21637	396.87217

Table 3.
Reductions in PM2.5 with tree planting by region

Probit model with data from the 2014 "National Health and Nutrition Survey". In particular, NO_x, SO_x and CO pollutants that affect PM2.5 formation and health were defined as environmental pollution indices (Cho and Son, 2004).

3.1 A Probit model

As the dependent variable of this analysis model was a binary variable, indicating whether doctors have diagnosed the patients or not, a Probit model or a Logit model can be used. These two models yield similar results but have a normal distribution and logarithmic distribution, respectively. The 6,000 samples from the personal health survey of 2014 (Survey on Public Health and Nutrition) was used in this research and it assumed to have a normal distribution. The model assigns a 1 when a patient visits a hospital because of respiratory or circulatory diseases caused by contamination from PM 2.5 and other environmental pollutants in the patient's social and economic conditions; otherwise, it assigns a 0. This binary variable (Y_i) is a dummy variable with either 0 or 1. Eqn (2) shows the Probit model.

$$Y^* = \beta X_i + \varepsilon_i, \ \varepsilon_i \sim \ N[0, 1] \tag{2}$$

where Y^* is an unobservable continuous variable, X is an independent variable vector and β is a vector for the estimated coefficient. Instead of Y^*, the observed dependent variable, Y has a value of either 1 or 0 depending on whether the event has occurred or not. Assuming that the error term, ε_i, follows the standard normal distribution, a Probit model is specified as in Eqn (3):

$$Y_i = \left\{ \begin{array}{l} 1 \ \text{if} \ Y_i^* > 0 \\ 0 \ \text{if} \ Y_i^* \leq 0 \end{array} \right\} \tag{3}$$

The probability distribution of an error term follows the normal distribution of equal variances and zero covariance. Therefore, it is based on the cumulative normal distribution probability function from a variety of cumulative probability functions (Cho, 1999). The probability of a disease occurring in the ith person, i.e. $Y_i = 1$, can be expressed as Eqn (4):

$$P[Y_i = 1] = P[\varepsilon_i > -X_i\beta] = 1 - \Phi(-X_i\beta) = \ \Phi(X_i\beta) = \ F(X_i) \tag{4}$$

where $\Phi(-X_i\beta)$ is a cumulative normal distribution function (CDF) of the error terms and $F(.)$ indicates the standard normal distribution. This model is represented by the log likelihood function, aiming to find vector β which maximizes the likelihood function $L(\beta)$ using the maximum likelihood method. Eqn (5) shows the logarithmic likelihood function:

$$\log L(\beta) = \prod_{Y_i=1} F(\beta X_i) + \prod_{Y_i=0} [1 - F(\beta_i X_i)] \tag{5}$$

These Probit model specifications with Eqs (2)–(5) are intended to capture the relationship between visiting patients and PM2.5. Then the model can further estimate economic benefits by associating with the reduction in their hospital expenses based on the amount of PM2.5 reduction by planted trees.

3.2 Data and the empirical model specification

Data used in the analysis are from the Health and Welfare Ministry's 2014 "National Health Impact Survey". The information regarding hospital visits resulting from respiratory and circulatory diseases was based on doctors' diagnosis from a basic database. The sample data collected during the year was 6,900. Among patients with genetic or inherent physical problems were excluded and the total sample of 6,888 were used this research. The sample

includes 519 patients who have visited a hospital for respiratory diseases and 1268 patents who have visited a hospital for circulatory diseases. The PM2.5 emissions were based on information provided by the National Institute of Environmental Research on pollutant emissions from each city/province in 2014 (National Weather Service, 2014). The average value of PM2.5 in each region was used, and for the SO_2, NO_2, CO pollutants, which are included in the environmental pollution index (PINDEX), we used average values measured for each region in 2014. Table 4 summarizes the descriptive statistics for the analysis.

Social conditions and characteristics of patients with diseases were extracted from the 2014 National Health and Nutrition Survey of the Basic database. The average number of hospital visits resulting from respiratory problems was 0.0753 per year and resulting from circulatory problems was 0.1841 per year. The age distribution of respondents was from age 1 to 80, with the average value between 42 and 43. The participants were divided into four groups depending on their income. Those with an income of less than 68 million won were assigned to the group "low," those of less than 148 million won into "medium-low," those of less than 250 million won into "medium-high" and those greater than 250 million won into "high." Education was also classified into four levels: "those who graduated an elementary school," "those who graduated a middle school," "those who graduated a high school" and lastly "those who graduated a university." Among the respondents, the number of people with a high school diploma or a lower level of education was relatively high. In 2014, the daily average of the highest temperature in the region was 16.15°C and the daily average of the lowest temperature was 11.69°C. During the same year, the highest relative humidity was 73.36% and the lowest was 57%.

Eqn (6) is an empirical equation that estimates the effects of changes in PM2.5 emissions on respiratory and circulatory diseases. Yi indicates whether the person has visited a hospital because of respiratory diseases (RESP) or circulatory diseases (CARDI).

$$Y_i = \beta_0 + \beta_1 \ln PM2.5 + \beta_2 PINDEX + \beta_3 AGE + \beta_4 AGE^2 + \beta_5 INCOME + \beta_6 EDU$$
$$+ \beta_7 TEMP + \beta_8 HUM + \beta_9 MARR + \beta_{10} SEX + u_i \tag{6}$$

Variable	Parameter explanation	Mean	Std. Dev	Min	Max
RESP	Hospital visit cause of respiratory disease (Yes = 1, None = 0)	0.08	0.26	0	1
CARDI	Hospital visit cause of circulatory disease (Yes = 1, None = 0)	0.18	0.39	0	1
lnPM2.5	Natural logarithm of PM2.5 emissions by region	7.79	0.96	5.76	9.53
PM2.5	PM2.5 emissions by region	3689.92	3499.46	318	13833
PINDEX	Environmental Pollution Index	−9.40	0.61	−11.75	−8.70
AGE	Respondent age	42.45	23.00	1	80
AGE2	Squared term of respondent age	331	1932	1	6,400
INCOME	Income quartile (low = 1, low-middle = 2, middle-high = 3, high = 4)	2.67	1.05	1	4
HUM	Relative humidity by region	66.48	4.07	57	73.36
TEMP	Average temperature by region	13.19	1.09	11.69	16.15
MARR	Marital Status (single = 0, married = 1)	0.67	0.47	0	1
EDU	Level of education (below elementary school = 1, below middle school = 2, below high school = 3, college or higher = 4)	2.03	1.40	1	4
SEX	Sex (man = 1, woman = 0)	0.55	0.50	0	1

Table 4.
Descriptive statistics analysis

The Environmental Pollution Index (PINDEX) is an environmental pollution index calculated by weighting SO_2, NO_2 and CO, pollutants, which are all harmful to the human body. PINDEX is included in the estimation equation because when the concentration of an individual contaminant is used as a descriptive variable, there is no significance because of correlations between the air pollutants. PINDEX was established using figures of SO_2, NO_2 and CO levels in the finalized data on air pollution by city and province from the Korea Environment Corporation. The average PINDEX by city was -9.40 and the values were between -11.75 and 8.70. Local PM2.5 emissions in 2014 were obtained from data provided by the National Institute of Environmental Research. The values were between 318 tons and 13,833 tons, showing a relatively large difference in emissions by region.

Variables that reflect the characteristics of the respondents' residential areas in the estimation equation include PM2.5 emissions (lnPM2.5), PINDEX, Temperature (TEMP) and Humidity (HUM). PM2.5 emissions were converted to a natural algebraic value to improve the regularity of analysis and obtain accurate values. Although PINDEX and lnPM2.5 were expected to show similar changes, it was believed that the former will be free from multicollinearity problems because the amount of contaminants varies from region to region. The frequency of hospital visits was expected to be relatively high in areas with more PM2.5 emissions or air pollution, which are often associated with the development of respiratory and circulatory diseases. Furthermore, the higher the temperature and humidity, the higher the incidence of dust and germs and the greater the likelihood of an incidence of the diseases.

Variables that reflect individual characteristics include age (AGE), secondary polynomial age (AGE^2), household income (INCOME), educational level (EDU), marital status (MARR) and gender (SEX). The risk of developing a disease was higher in the younger or older age groups. However, the incidence of the diseases was lower for young and middle-aged people. Since the age variable can be non-linear, the square term of age is included as an independent variable to meet linear assumptions. Therefore, a second-order polynomial variable of AGE was included.

The effect of household income is uncertain. Higher incomes may lead to lower rates of hospital visits, but better health insurance coverage may serve as a more frequent incentive in terms of hospital accessibility and costs. Conversely, those with low incomes may have relatively high rates of hospital visits because of a high risk of exposure to various contaminants along with nutritional imbalances. However, the opposite may also be true owing to a low level of protection provided by health insurance.

Because people with high educational levels are more likely to have jobs with lower demands for outdoor activities, they are less vulnerable to respiratory diseases. However, those with long sitting hours may have a relatively high incidence of circulatory diseases. In the same manner, people with a lower level of education may be relatively more vulnerable to respiratory diseases.

Marriage may have tradeoffs, as income levels do. A relatively high level of health care and health insurance that married people can afford can serve as both negative and positive factors in the frequency of hospital visits. In terms of gender, women are more vulnerable to circulatory diseases than men because they spend longer hours at home. However, men are more likely to have hospital visits resulting from respiratory problems because they are more socially active.

4. Discussion and implications
The effects of PM2.5 emissions on respiratory (RESP) and circulatory (CARDI) diseases were estimated using a Probit model as shown in Table 5. STATA statistical programs were used to estimate the model.

Variables	PESP	Marginal effect	CARDI	Marginal effect
lnPM2.5	0.1910*** (0.0400)	0.0163*** (0.0034)	0.201*** (0.0452)	0.0068*** (0.0016)
PINDEX	0.1430* (0.0800)	0.0122* (0.0068)	0.1450* (0.0876)	0.0049* (0.0030)
AGE	0.0520*** (0.0059)	0.0044*** (0.0005)	0.0629*** (0.0074)	0.0021*** (0.0003)
AGE^2	-0.0006*** (6.07e-05)	-4.96e-05*** (5.50e-06)	-0.0006*** (7.08e-05)	-1.89e-05*** (3.13e-06)
MARR	-0.3060*** (0.1030)	-0.0288*** (0.0107)	-0.4870*** (0.1310)	-0.0204*** (0.0069)
INCOME	-0.0163 (0.0258)	-0.0014 (0.0022)	-0.0659** (0.0299)	-0.0022** (0.0010)
HUM	0.0059 (0.0075)	0.0005 (0.0006)	-0.0169** (0.0086)	-0.0006* (0.0003)
TEMP	-0.1080*** (0.0308)	-0.0092*** (0.0026)	-0.1550*** (0.0340)	-0.0052*** (0.0012)
EDU	-0.4440*** (0.0209)	-0.0378*** (0.0019)	-0.6550*** (0.0304)	-0.0221*** (0.0019)
SEX	-0.0405 (0.0500)	-0.0035 (0.0043)	-0.2500*** (0.0576)	-0.0088*** (0.0022)
Constant	-0.6910 (1.0070)	–	0.9660 (1.1510)	–
Observations	7,508	7,508	7,508	7,508

Note(s): 1. Standard errors in parentheses
2. ***, **, * are significant at levels of 1, 5, and 10%
3. PESP: Hospital visit variable cause of respiratory disease; CARDI: Hospital visit variable cause of circulatory disease

Table 5.
Effects of PM2.5 on respiratory and circulatory diseases

The estimated results show that PM2.5 has statistically significant effects on hospital visits resulting from respiratory and circulatory diseases, both of which are closely associated with PM2.5 emissions. That is, PM2.5 emissions increase hospital visits resulting from the respiratory and circulatory diseases. Furthermore, respiratory diseases are more likely to develop than the circulatory diseases because of the PM2.5 emissions.

The estimated (+) coefficient value for the PINDEX variable suggests that pollutants other than PM2.5 in the atmosphere also affect the frequency of hospital visits resulting from respiratory and circulatory diseases. The age (AGE) and secondary polynomial (AGE^2) coefficients were positive (+) and negative (−), respectively, meaning respiratory and circulatory disorders increased as age increased. Another interpretation of the results is that the prevalence rate among older children was lower than that of older adults. This is because children are not as socially active and they spend longer hours indoors. In other words, they stay under the protection of parents and health care.

Income variables are shown to have a significant effect on circulatory diseases. This is predictable as those with higher incomes can visit hospitals more often. However, this result was not statistically significant for the respiratory system. Temperature (TEMP), an important variable for weather, was negative (−) as expected, meaning that PM2.5 concentrations decreased as the wind velocity increased at high temperatures and fine dust was dispersed (Luo *et al.*, 2017). In addition, temperature may affect PM2.5 concentrations by promoting the evaporation of ammonium nitrate into the atmosphere and also by influencing the amount of emissions from domestic heating and electricity power plants (Tai *et al.*, 2010). In addition, this reflects a larger amount of fine dust being removed during summer rainfall and also fine dust increasing in concentration during spring and winter. Relative humidity, however, has a statistically significant effect (−) only on the circulatory system, as expected.

Marriage variables show significant effects on hospital visits for both diseases. They have negative effects, indicating that unmarried people have relatively frequent visits. Regarding the level of education, both diseases had negative coefficients and showed statistically significant results. This suggests that people with lower education levels are relatively more exposed to the diseases because of their jobs and other factors. For example, a person with a low level of education may be more vulnerable to the diseases because they are mainly work at dusty construction sites or complete outdoor work. Gender variables show statistically significant negative signs for the circulatory system. Some interpretations are that women are more susceptible to circulatory diseases than men, more susceptible to the environment, more likely to visit hospitals because of their physical characteristics or more health-conscious than men (Shin *et al.*, 2008).

Marginal effects of PM2.5 emissions associated with hospital visits resulting from respiratory and circulatory diseases were calculated as 0.0163 and 0.00676, respectively. In other words, when PM2.5 emissions increase by 1%, the probability of hospital visits resulting from respiratory diseases increases by 1.63% and the probability of hospital visits resulting from circulatory diseases increased by 0.68%. In addition, the marginal effect of a 1% increase in PINDEX was estimated to be a 1.22% increase in respiratory diseases and a 0.49% increase in circulatory diseases.

A 1% increase in age and related PM2.5 emissions was found to increase the frequency of hospital visits resulting from respiratory diseases by 0.44% and increase the frequency of hospital visits resulting from circulatory diseases by 0.21%. Individuals with lower education levels showed relatively high marginal effects of PM2.5 emissions; 3.78 and 2.21%, respectively, for respiratory and circulatory diseases. Finally, for single people, an increase in PM2.5 emissions increased hospital visits by 2.88% for respiratory diseases and by 2.04% for circulatory diseases.

Table 6 summaries the health benefits in terms of decreases in patients and the money savings. The marginal effects of the estimated PM2.5 emissions multiplied by the total

population of 50.7 million in 2014 yield the change in the number of hospital visiting patients (Korea Statistics, 2014). More specifically, a 1% decrease in PM2.5 emissions leads to fewer patients with respiratory and circulatory diseases by 827,439 and 343,159, respectively. Given the country's 63,286 tons of the total PM2.5 emission level, these patient numbers are equivalent to 1,307 and 542 with a 1-ton decrease in PM2.5 emissions, respectively (National Air Pollutants Emission Service, 2014).

According to the Health Insurance Review Assessment Service of the Centers for disease Classification and Information, the cost of hospitalization or hospital visits resulting from respiratory and circulatory diseases was 54,732 won and 43,790 won per person as of 2014, respectively (Korea Centers for Disease Control and Prevention, 2014). It can be thus estimated that a 1 ton decrease in PM2.5 emissions will reduce annual medical expenses related to respiratory and circulatory diseases by 72 million won and 24 million won, respectively.

The aforementioned results can be combined with the Korea Forest Service, 2018 Forestry Statistics to estimate the health benefits of PM2.5 reductions for each age group of the trees and the numbers of patients with respiratory and circulatory diseases. Table 7 shows health benefits calculated for the diseases. The total health benefits of PM2.5 reductions after planting trees were 481 million won, 173 million won and 1,027 million won for 2-year-old Red Pine, Pinus Koraiensis and Quercus, respectively. If the trees are 80 years old, the benefits are estimated to be 73 billion won, 103 billion won and 38 billion won, respectively.

5. Conclusion

Forests and trees in cities provide public utility functions, including catching and absorbing air pollutants from roads and factories. In particular, considerable attention has been paid to the imperative task of reducing carbon dioxide emissions and the positive effects trees can yield. Based on the scientific results from prior studies on PM 2.5 adsorption, we quantified PM2.5 adsorption volumes of three trees species that are typical in Korea. Then, we estimated the possibility of developing respiratory and circulatory diseases once the level of PM2.5 emissions changed. Lastly, we presented the health benefits of lowered PM2.5 emissions resulting from planting of trees.

The trees of interest were Red Pine, Pinus Koraiensis and Quercus and their PM2.5 accumulation and removal volumes varied depending on their age. Based on to the 2018 tree planting plan (Korea Forest Service, 2018), if we assume that all 2-year-old trees planted are

Disease classification	Decrease in patients	Benefits (mill. won)
Respiratory diseases	1,307	71.5
Circulatory diseases	542	23.7
Total	1,849	95.2

Table 6.
Estimates of health benefits given a 1-ton reduction in PM2.5 emissions

Age	Respiratory disease (mill. won)			Circulatory disease (mill. won)		
	Red pine	Pinus Koraiensis	Quercus	Red pine	Pinus Koraiensis	Quercus
2	361	130	771	120	43	256
10	3,118	1,513	3,938	1,034	502	1,307
20	8,700	9,717	7,073	2,887	3,224	2,347
40	23,580	40,112	13,743	7,823	13,309	4,560
60	39,610	65,837	20,975	13,142	21,844	6,959
80	54,873	77,582	28,390	18,206	25,741	9,419

Table 7.
Estimates of yearly health benefits by diseases and tree

Red Pine or Pinus Koraiensis or Quercus, the PM2.5 adsorption rate was 5.0 tons for Red Pine, 1.8 tons for Pinus Koraiensis and 10.8 tons for Quercus. However, the PM2.5 adsorption rate varies depending on the characteristics of each tree species, its growth and the number of leaves on the trees. In the case of 80-year-old trees, Red Pine recorded the highest adsorption rate of 767 tons, followed by 1,085 tons for Pinus Koraiensis and 397 tons for Quercus. The results suggest that once the trees are planted and as they age, coniferous trees are more effective in removing PM2.5 than deciduous trees.

Health benefits of the reduction in PM2.5 emissions were estimated using a Probit model. The analysis showed that if PM2.5 emission level increases by 1%, the probability of a patient visiting a hospital with a respiratory or circulatory disease increases by 1.6 and 0.7%, respectively. The total health benefits of reducing PM2.5 emissions were calculated using medical expense data for the respiratory and circulatory diseases and amounted to 95.3 million won.

Based on these two conclusions, the health benefits of the PM2.5 reductions on respiratory and circulatory diseases were calculated. The health benefits for the respiratory diseases were approximately three times higher than those for the circulatory diseases. In addition, as with the previous results, the health benefits of Quercus were approximately six times higher than those of Pinus Koraiensis for the young trees. However, for the old trees, the health benefits of Pinus Koraiensis were approximately three times higher.

Based on the results that the health benefits for hospital visits resulting from respiratory and circulatory system diseases vary greatly depending on the tree species and the age of tree, it can be concluded that Quercus, a deciduous tree species, is advantageous for short-term effects but Pinus Koraiensis is particularly beneficial among coniferous species. In addition, the health benefits from planting trees are more effective in reducing respiratory diseases than circulatory diseases. These results not only convey important information regarding tree species in the creation of urban forests in the future, but they also suggest that among the various public utility functions of trees, PM2.5 reduction plays an outstanding role from an environmental aspect.

One limitation of this study is that the weight of PM2.5 adsorbed by each leaf area entirely depended on the experimental results from a prior study and the values are likely to be different from those actually absorbed in natural surroundings. In addition, because of the lack of data from a domestic survey on the surface of leaf area or the reload flow rate of PM2.5, this study referred to data from foreign research. Unfortunately, this specific data may not reflect climatic and terrain characteristics specific to the target country. We used the annual wind speed to calculate the reload flow rate and elimination volume; however, the figures could be more accurate with hourly or daily climate variations. When estimating the health benefits of changes in PM2.5 emissions on respiratory and circulatory diseases, more segmented access to patients' hospital visits and hospital admissions are desirable. Finally, the study focused on the three major tree species of Korea, however, a more detailed study of PM2.5 reduction by various tree types is needed in the future.

Note

1. Based on the previous studies, the adsorption amount of PM2.5 by the *Pinus massoniana*, a pine coniferous tree, was used for the Red Pine and Pinus Koraiensis. The adsorption amount of PM 2.5 by the *Sophora japonica*, a dicotyledonous of broad-leaf family closely related to Myrsinaleaf Oak, was used for the Quercus.

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