Impact of Comprehensive Smoke-Free Policies and Outdoor Smoking Bans on Smoking in South Korea: A Synthetic Control Approach

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Abstract

In 2011, South Korea implemented comprehensive smoke-free policy (SFP) and outdoor smoking ban, enforcing a complete smoking ban in various public places, including public transport, government buildings, medical facilities, nurseries, schools, large restaurants, bars, and theaters. Smoking was permitted only in specially designated smoking rooms, and violators were subject to fines. This was a significant shift from the policy established in 1995, which required designated establishments to offer separate smoking and non-smoking sections. To causally estimate the effect of the policy, we used a synthetic control group approach, comparing South Korea to a synthetic South Korea that did not implement the comprehensive SFP and outdoor smoking bans using data from 28 other high-income countries from 1995 to 2015. The results indicated that the comprehensive SFP and outdoor smoking bans effectively reduced smoking prevalence by an average of 2.3 percentage points from the 2011 smoking rate of 27.1%, representing an 8.5% reduction ($p < 0.036$). In practical terms, the comprehensive SFP and outdoor smoking bans deterred approximately 1.2 million people from smoking, either by encouraging current smokers to quit or preventing new smokers from starting.

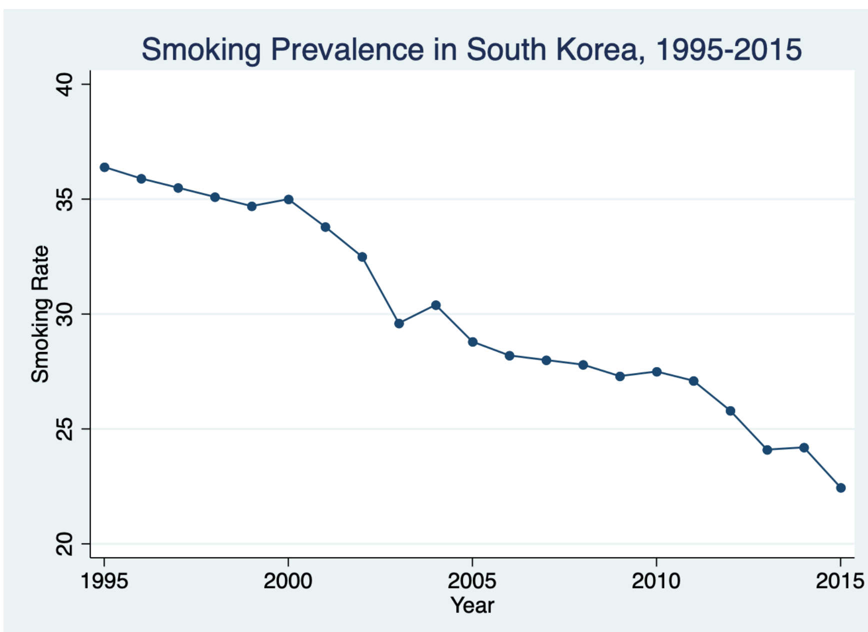
Keywords: Observation studies, Tobacco Control Policy, Synthetic Control Methods
JEL Codes: I18, H51

Contents

1 Introduction

Smoking is a major concern for policymakers in South Korea. The average smoking rate recorded 35%[1] in 2000, 62.8% among the male population and 7.1% among the female population. South Korea is the 7th highest male smoking rate in OECD countries based on 2017 OECD Health Statistics estimates (Figure 2). According to Jung et al. (2013), approximately 58,000 people experience premature death related to smoking each year. Also, Oh et al. (2012) using the nationally representative claims data from the National Health Insurance Corporation, estimated the total economic cost of smoking-related cancers reached $3 billion in 2008.

Figure 1: Average Smoking Rates in South Korea from 1995 to 2015

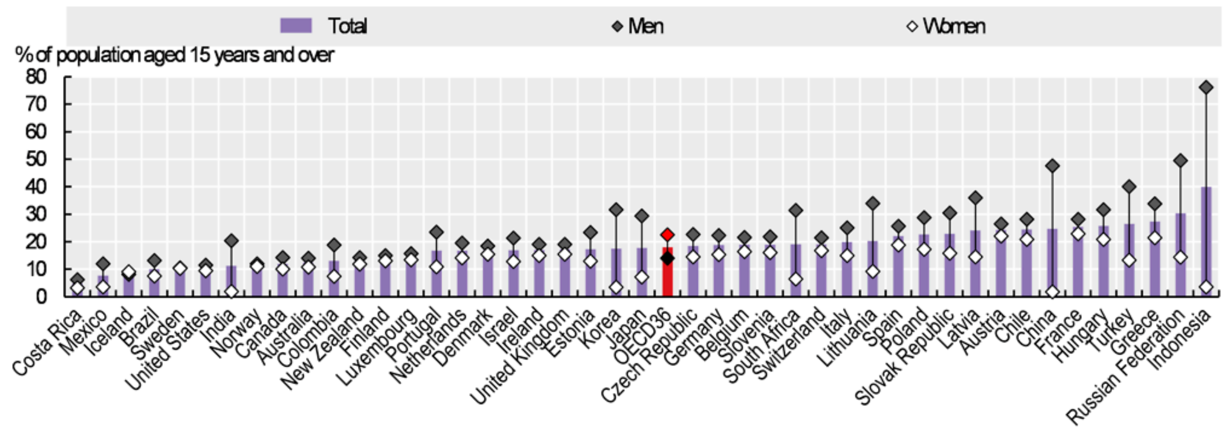


Note: The data is based on the Korea National Health and Nutrition Examination Survey (KNHANES), a survey question of 'Are you currently smoking?' to indicates whether an individual has been smoking in the past 30 days. The prevalence represents the share of the general population aged 19 years or older who reported to currently smoking.

Reducing the smoking prevalence could help reduce substantial amount of national healthcare spending and prevent individual health problems. The South Korean government has

[1] The smoking prevalence represents the share of the general population aged 19 years or older who reported currently smoking. *Source*: KNHANES

Figure 2: OECD Countries Average Smoking Rates in 2017



Note: The smoking prevalence among male population is highest in Indonesia, followed by Russia, China, Turkiye, Latvia, Lithuania, and Korea. *Source*: OECD Health Statistics

made a great effort to reduce the prevalence of smoking and its consumption, especially starting from 2011 when the government observed a steady increase in the smoking rate. The amendment of National Health Promotion Act that passed in 2010 gave local authorities the power to enact bylaws banning smoking in outdoor public places (Cho, 2014). However, the expansion of outdoor smoke-free areas only began after the Seoul Metropolitan Government passed a bill in 2011. As a result of the amendment, the smoke-free zones expanded to include public areas such as bus stops, subway station entrances, and public parks. Another amendment in 2011 passed a comprehensive indoor smoke-free law, requiring a completely isolated smoking booth for indoor smoking[2]. The comprehensive smoke-free policy (SFP) was first introduced in large restaurants, bars, cafes, and offices, which later expanded to all restaurants, bars, cafes, and offices. Fines of 100,000 Won ($90.10[3]) were imposed on those who violated the SFP. Police officers and government officials were actively enforcing the fines on smokers who smoked in the prohibited area[4].

In 2015, policymakers doubled the cigarette tax, raising cigarette price by 80%, from

[2]Under the partial indoor smoke-free law, it was only required to divide a space into two areas: a smoking zone and a non-smoking zone, leaving non-smokers vulnerable to second-hand smoke. See figure 3.

[3]Based on the exchange rate of 1 U.S.D to 1,100 Korean Won

[4]Table 1 illustrates increasing enforcement over time.

Figure 3: Illustration: Partial vs Comprehensive Smoke-free Law

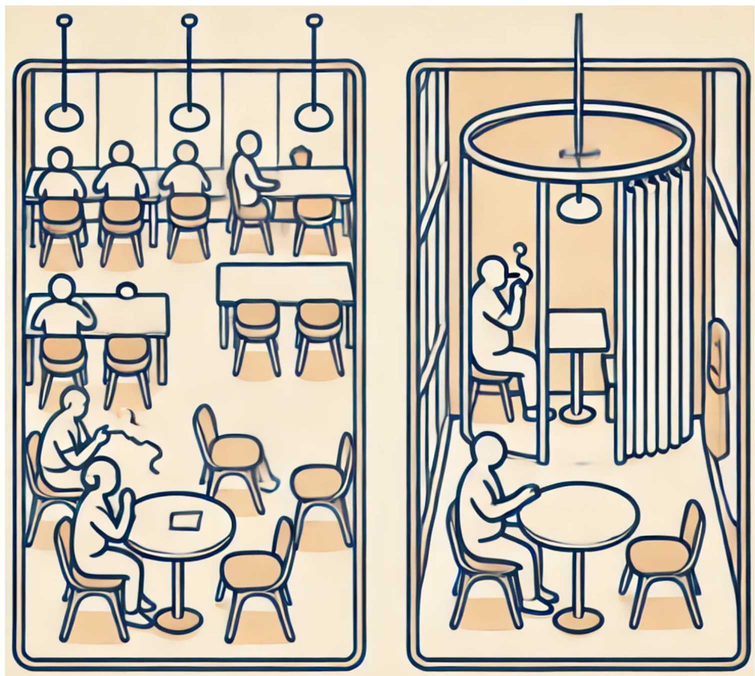


Table 1: Number of Enforcement

Year	2012	2013	2014	2015	2018
Number of fines enforced					
Nationwide	-	27,533	-	57,708	61,830
Seoul	11,387	25,653	38,045	40,229	-

Source: Seoul Open Data Plaza, Ministry of Health and Welfare of South Korea

2,500 Won ($2.30) to 4,500 Won ($4.10). In 2016, the Korean government passed a law to mandate to include pictorial warning labels (Figure 4) on all cigarette packages. In 2017 and 2018, the smoke-free zone expanded to all sports facilities and kindergarten areas.

Figure 4: Example of Picture Warning Labels

Note: The pictures above are three examples out of twelve pictorial warning labels. Consumers receive random pictorial warning labels out of twelve samples. Pictures are renewed every two years to prevent consumers from adaptation to existing warning labels.

Studies have shown that comprehensive SFP in Korea led to increased indoor air quality, and reduced second-hand smoke which are the primary intention of the policy. Kim et al. (2016) measured indoor air quality of 148 bars located in Seoul and Changwon before and after the implementation of comprehensive SFP, found that $PM_{2.5}$ concentration of all bars gradually decreased from 98.4 $\mu g/m^3$ to 26.6 $\mu g/m^3$. Park et al. (2020) examined biochemical markers specific to second-hand smoke to measure the exposure under different smoking restriction settings. The authors concluded that comprehensive indoor smoking bans reduced second-hand smoke in hospitals, internet cafes, karaoke, and billiard halls. These findings are align with the findings in New Zealand (Edwards et al., 2008).

However, literature on the effect of comprehensive smoking bans on smoking rates provides mixed evidences. Boes et al. (2015) exploits the progressive implementation of smoking bans in public venues in Switzerland, found the reduction of smoking prevalence by 1% after a year of implementation. Anger et al. (2011) used state variation of smoke-free implementation in bars in Germany. The authors found that people who go out to bars often reduced smoking, but no change in average smoking behavior within the population. In the United States, Carton et al. (2016) using Behavioral Risk Factor Surveillance System (BRFSS) data found the comprehensive indoor smoking bans are associated with a 2.35% to 3.29% average reduction in smoking prevalence.

On the other hand, Lee, Glantz, and Millett (2011) studied the implementation of SFP in England, found significant reduction of smoking behavior in prohibited area which led to a reduction in smoking prevalence. However, they concluded that the reduction was barely the trend, suggesting that the SFP did not accelerate nor decelerate smoking prevalence reduction. Several studies suggest that there are no clear evidence of SFP effect on smoking prevalence, but it increases quitting attempts (Nagelhout et al., 2012; Edwards et al., 2008).

Kang and Cho (2020) and Ko (2020) investigated the impact of comprehensive SFP and outdoor smoking bans on smoking behavior. Kang and Cho (2020) found a significant decrease in adolescent smoking prevalence among boys from 16% to 9%, and among girls from 9% to 3% between 2006 and 2017. Ko (2020) exploits the variation in implementation of outdoor smoking bans at the local government level, found it increased the probability of making a quit attempt by 16% which conforms to previous studies of Nagelhout et al. (2012), and Edwards et al. (2008). However, Ko (2020) found no evidence on the effect of the outdoor smoking ban on smoking prevalence.

Given the mixed evidence of the behavioral impacts of comprehensive SFP, investigating the impact of SFP in South Korea would be valuable to the literature on SFP by providing important insights into their effectiveness in different cultural and policy contexts. However, studies that examined the effects of SFP in South Korea (Kim et al., 2016; Park et al., 2020; Kang and Cho, 2020) used pre-post analysis which may result in biased estimates of the causal effect of the policy due to uncontrolled nation-specific, time-varying heterogeneity. Ko (2020) causally estimated the effect of the outdoor ban, however, the effect on smoking prevalence may have been influenced by nation-specific policy controls, including the 2011

SFP.

In theory, as SFP being implemented, the cost of smoking increases both physically and mentally. Restrictions reduce smokers' opportunity to consume tobacco products, requiring them to invest additional time in finding a smoking area. Additionally, the passage of comprehensive smoke-free laws may shifted social norms regarding the acceptability of indoor smoking (Kim et al., 2018), creating a stigma around smoking behavior. This may increase the mental cost of smoking. However, if the cost is not high enough to counter the addiction, smokers may continue to smoke. Given that the cost of smoking increases progressively with the implementation of both indoor and outdoor smoke-free restrictions, analyzing the combined impact of SFP and outdoor smoking bans is plausible when estimating the reduction in smoking prevalence. The growing body of literature on causal inference suggests that the synthetic control method could provide valuable insights in this context.

In this paper, I empirically estimate the effect of the comprehensive SFP and outdoor smoking bans in South Korea by estimating the reduction in the average smoking rates using country-level panel data and the synthetic control method (Abadie and Gardeazabla 2003; Abadie, Diamond, and Hainmueller 2010; 2015; Andersson, 2019; Abadie, 2021). My study period ends in 2015 to avoid confounding my causal estimates with other tobacco control policies[5]. From a group of OECD countries, I construct the counterfactual, "Synthetic Korea:" a comparable unit consisting of a weighted combination of countries that did not implement a sequence of large price policies and non-price policies during the treatment period and that, prior to treatment, resemble Korea on several key predictors of smoking rates and have similar levels and paths of smoking rates. The synthetic control method estimates an average smoking rate reduction of 2.3 percentage points from the baseline smoking rate of 27.1 percent in 2011, which is an 8.5 percent reduction. In other words, the comprehensive SFP and outdoor smoking bans effectively deterred 1.2 million people from smoking, either through cessation of the current smokers or preventing the initiation of new

[5] Such as the increase in cigarette tax in 2015 and the implementation of pictorial warning labels on cigarette packages in 2016.

smokers.

The remainder of the paper is organized as follows. Section 2 presents detailed background on South Korea's tobacco control policies. Section 3 presents the data and methods used for the estimation of smoking prevalence reductions. Section 4 presents the results of the empirical analysis as well as several robustness checks. Finally, section 5 concludes.

2 Backgound

Smoking cigarettes was very common among male adults in 1990,with a smoking rate of 75.3%, while only 7.7% of female adults smoked, bringing the overall average down to 41.5%. There was a strong social norm that women should not smoke cigarettes. In 1995, South Korean policymakers began to recognize smoking as a serious problem and enacted the National Health Promotion Act, which included tobacco control policies such as designating schools and hospitals as smoke-free zones and restricting the advertisement and exposure of tobacco products on television (Cho, 2014). Table 2 describes the changes in cigarette tax and price from 1991. Cigarette taxes increased gradually from 1994 to 2002, followed by significant hikes in 2002 and 2005, each raising tobacco prices by 500 Won (a 60% increase). This led to a rapid decrease in smoking prevalence among the male population, from 60.5% in 2002 to 45.9% in 2006. However, the effect of the initial price increase soon diminished, resulting in a steady rise in smoking prevalence among both male and female populations.

Table 2: Cigarette Tax and Price Changes in South Korea

Year	1991.1	1994.1	1996.7	1997.5	1999.1	2001.1	2002.2	2002.8	2005.1	2015.1
Cigarette Tax (Won)	360	480	648	650	750	889	1065	1111	1565	3318
Cigarette Price (Won)	600	900	1000	1100	1100	1300	1500	2000	2500	4500

Source: Park (2016)

Although South Korea ratified the WHO Framework Convention on Tobacco Control (FCTC), the efforts to regulate smoking have been weak (Cho, 2014). Tobacco advertising, promotion, and sponsorship are not comprehensively restricted, the sale of tobacco products to minors is poorly enforced, though it is prohibited, and smoking cessation services are not covered by the public health insurance program.

Starting in 2011, the South Korean government shifted its stance and implemented a series of tobacco control policies. The National Health Promotion Act was amended in 2010, granting local authorities the power to establish regulations prohibiting smoking in outdoor public spaces (Cho, 2014). Although the amendment was made in 2010, the significant expansion of outdoor smoking bans gained momentum after the Seoul Metropolitan Government passed a bill to prevent secondhand smoke in 2011. This led to the expansion of smoke-free zones to various public areas, including commonly frequented sites such as bus stops, subway station entrances, and public parks[6]. In 2011, another amendment to the National Health Promotion Act introduced a comprehensive indoor smoke-free policy. Prior to this, since 1995, it was only required to have separate areas for non-smokers in indoor spaces, which did not effectively prevent second-hand smoke. However, after 2011, all indoor spaces covered by the amendment became non-smoking zones, except for smoking booths, which are completely isolated areas[7]. A new fine of 100,000 Won ($90.10) was introduced and actively enforced on people who smoke in the prohibited area.

The introduction of the indoor smoke-free policy in 2011, prohibiting smoking in large restaurants, bars, cafes, and offices, later expanded to all restaurants, and bars made smokers substantially inconvenient to smoke[8]. People's perceptions of smoking and the social norm dramatically changed around this time. Park et al. (2019) uses the International Tobacco Control (ITC) Korea Survey to investigate the attitudes of smokers towards smoking behavior. The authors suggest that Korean smokers became more supportive of smoking bans in public places.

In 2015, the cigarette tax doubled raising cigarette price by 80% from 2,500 Won ($2.30)

[6]No-smoking signs are installed in smoke-free zones. See figure 5

[7]See figure 6 and 7.

[8]Table 3 shows the number of smoke-free areas nationwide. The number of no-smoking zones increased substantially after the policy was implemented.

Figure 5: Example of No Smoking Sign

Figure 6: Examples of Smoking Booth for Indoor

Figure 7: Examples of Smoking Booth for Outdoor

Table 3: Expansion of Smoke-free Area

Year	2012	2013	2014	2015	2016	2017	2018
Number of Smoking-free Sites	398,545	664,992	688,321	1,278,343	1,334,473	1,452,540	1,527,987

Source: Kim (2019)

to 4,500 Won ($4.10). The graphic warning labels (figure 4) are mandated to be included in the cigarette package in the following year. Smoke-free zones continued to expand, and by 2018, they covered most indoor areas, public spaces, schools, hospitals, kindergarten areas, and sports facilities.

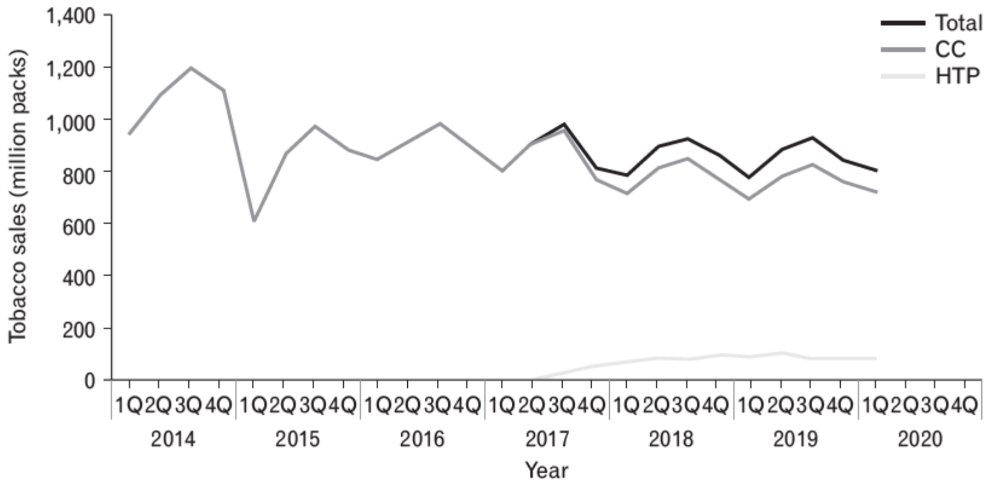
While the previous discussion focused on the policy side of cigarette uses, it is also important to consider the market dynamics that influence smoking behavior. The introduction of non-conventional cigarettes, such as electronic nicotine delivery systems (ENDS) and heated tobacco products may reduce the observed smoking prevalence when conventional cigarette users switch to these alternatives. According to data from the Korea National Health and Nutrition Examination Survey (KNHANES), the prevalence of e-cigarette use among adult was 0.9 percent in 2013, 1.4 percent in 2014, and 2.6 percent in 2015[9] (Sung, 2018). Heated tobacco products (HTP) were introduced to the market in 2017. Figure 8 displays the quarterly sales trends of conventional tobacco products and HTP[10] (Lee, 2020).

Several studies researched the effect of the tobacco price policy in 2015 since the increase was huge. Kim and Kim (2017) and Han (2019) estimated that the tobacco tax increase in 2015 reduced the average smoking rate by 3%. Lim and Khang (2021) found that low-income Korean smokers were more responsive to changes in tobacco prices. Jeong Da-hae (2020) found that education level and income level were significantly higher among non-smokers than smokers in 2018. Cheon et al. (2021) reports no changes in smoking habits among Korean male cancer survivors. Only temporary effect on the stage of smoking cessation among Korean male smokers (Kwon et al., 2021).

[9] However, the increasing prevalence of e-cigarettes may not significantly affect our results due to the high rate of dual use between conventional cigarettes and e-cigarettes (Jeon et al., 2016).

[10] Since my study period end in 2015, HTP uses does not affect my estimates.

Figure 8: Quaterly Sales Trend of Conventional Cigarette and Heated Tobacco Products



Source: Lee (2020)

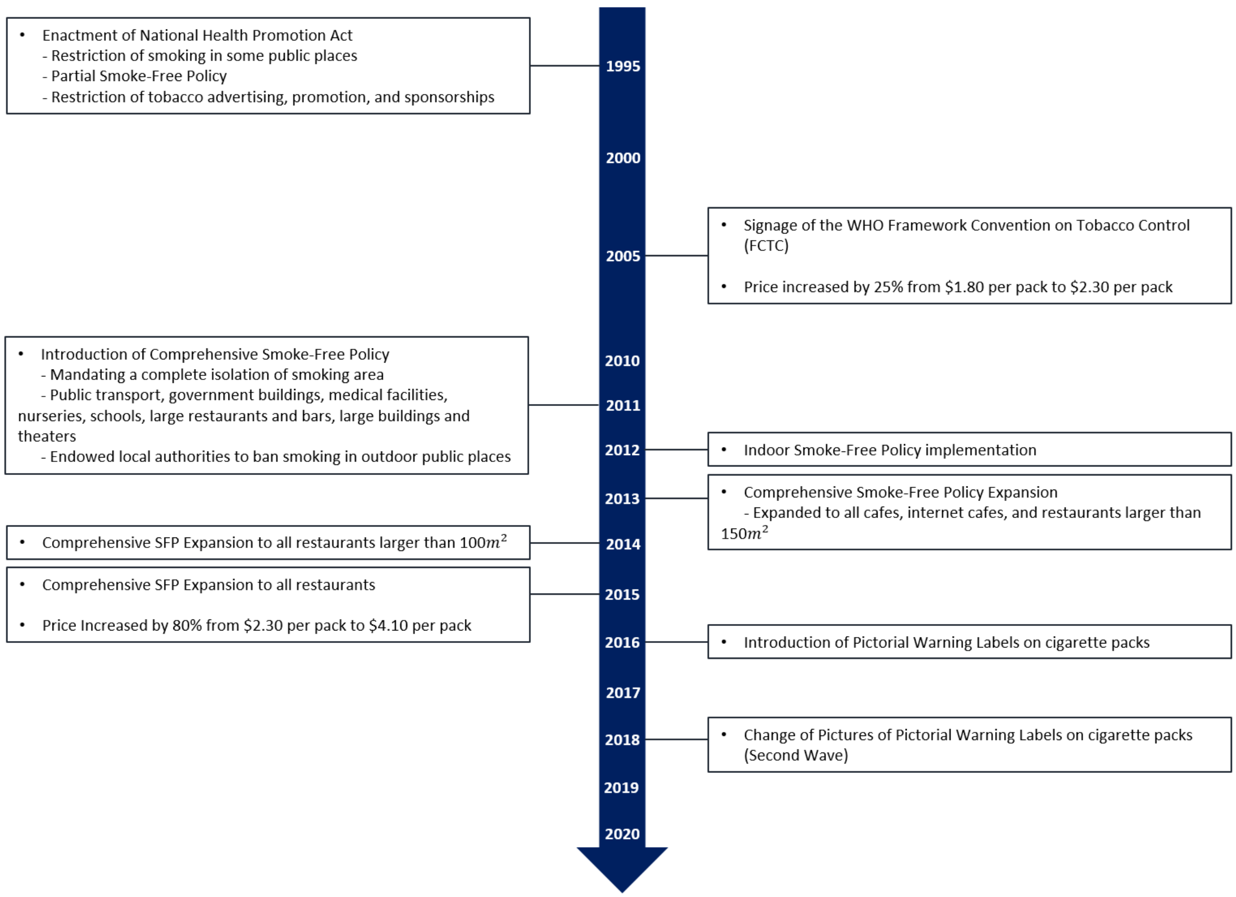
As in Levy et al. (2004), a large increase in cigarette taxes and the passage of comprehensive clean air laws are the cornerstone of strategies that have been successful in reducing smoking rates. South Korea implemented comprehensive clean air laws in 2011 and increased tobacco taxes by twice in 2015. As a result, smoking prevalence dropped from 27.1% in 2011 to 23.9% in 2015. There are some studies examining the effect of tobacco control policies using pre-post analysis. This paper attempts to causally estimate the treatment effect of comprehensive SFP and outdoor smoking bans in South Korea, and provide insights into the empirical methodology of policy evaluation when the policy was implemented nationally and simultaneously.

3 Empirical Methodology

3.1 Data

To empirically analyze the effect of the comprehensive SFP and outdoor smoking bans implemented in 2011 on smoking prevalence, I use annual country-level panel data for the period 1995-2015. My data includes 28 OECD countries including South Korea based on the

Figure 9: Timeline of Tobacco Control Policies in South Korea, 1995-2020.



Source: Cho (2014)

availability of smoking prevalence data. The smoking prevalence data is obtained multiple resources including International Smoking Statistics (Forey et al., 2006), World Development Indicators (WDI) data by World Bank, and World Health Organization (WHO) tobacco use data. I use Korea National Health And Nutrition Examination Survey (KNHANES) data for Korean smoking prevalence. Despite the inconsistency among other countries, I try to extract a consistent measure of the smoking rate by restricting to those who are above 15, and have smoked manufactured cigarettes in the last month. However, not every country surveys the smoking rate every year, thus there are several missing data points. I assumed a linear trend between the missing data points. For the national indicators, I used World Development Indicators (WDI) data. The data on national indicators include GDP per capita, age distribution, industry composition, and alcohol consumption per capita. The sample period begins in 1995 and the comprehensive SFP and outdoor smoking bans started in 2011, providing 17 years of pre-intervention data. I restricted my study period to 2015 to avoid confounding my causal estimates with other policies, such as the cigarette tax increase in 2015 and the implementation of graphic warning labels on cigarette packages in 2016. However, the sample period still provides 5 years of post-intervention data which would be sufficient to observe the treatment effect of the policy changes.

From the initial sample of 37 OECD countries, excluding South Korea, 10 countries were excluded since there is no consistent data on smoking prevalence. Excluded countries are Chile, Colombia, Costa Rica, Latvia, Lithuania, Luxembourg, Mexico, Slovak Republic, Slovenia, and Turkiye. Thus, in the end, my donor pool consists of 27 countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, France, Finland, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Israel, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, the United States, and the United Kingdom. Table 4 shows smoking prevalence in 27 countries between 1995 and 2015.

Table 4: Smoking Prevalence by Country

	Year																				
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Smoking Rates:																					
Australia	25.6	25.8	26	26.4	23	24.3	24.3	23	21.8	20.6	21.1	20.4	19.7	18.9	18.5	18.2	17.5	16.9	16.3	16	15.7
Austria	35.3	33.5	32.2	31.7	31.8	32.1	31.6	31	31.3	30.3	29.4	28.8	29.3	29.7	30	30.1	29.5	29.5	29.2	28.4	27.1
Belgium	36.3	33.8	30.1	30	30.6	29.7	28.9	30.7	29.4	27.2	27.8	25.9	26	25.7	26	26.2	25.8	25.9	26.2	25.9	25.7
Canada	27.5	26	25.8	26	25.2	24.4	21.7	21.4	20.9	19.6	18.7	18.6	19.2	17.9	17.5	16.7	17.3	16.1	16	15.9	15.8
Czechia	36.6	36.3	36	35.5	35	34.2	33	31.9	31.7	31.5	31.4	28.8	27.4	26.7	26.45	26.4	27	29.2	29.5	29.7	29.9
Denmark	42.6	37.5	35	35.7	36.1	34.2	33.8	31	30	26.6	28.1	27.7	28	27	26	24.9	23.9	23.1	22.2	21.6	21.1
Estonia	37.5	38.1	38.8	38.2	37.2	36.9	36.8	35.4	35	34.6	33.8	33.6	34.4	35.4	36.1	37.2	36.5	35.5	34.7	33.8	33.3
France	36.4	35.3	35	33.9	33.8	34.2	36	33.6	34.4	33.7	32.8	32.8	32.9	33	33.2	33.4	33.3	33.4	33.4	33.4	33.2
Finland	28.9	28	28.9	28.7	28.6	29.7	29.1	29.3	28	27.3	26.3	24.7	25.7	24.2	23	22.6	22.5	22	21.7	21.9	21.5
Germany	38.5	36.8	35.7	34.1	33.1	32.7	32	32.5	32.2	31	30.9	30.9	29.5	28.4	28	27.2	25.8	25.6	25.3	26.4	24.9
Greece	44.6	44.2	44.3	44.7	45.3	44.1	43	41.9	41.3	40.9	40.7	39.3	39.5	40.1	40.05	38.25	38.8	39.6	39	38.6	37.9
Hungary	35.6	35.9	36.3	35.6	35.4	33.6	33.9	33.9	32.8	29.8	30.7	32.8	31.8	33.8	31.4	33.3	34.1	33.8	33.2	32.9	33.2
Iceland	32.3	31	30.8	31.3	30.4	27.5	26.1	25.4	25.4	24	22.6	22.2	22.6	20.9	18.8	18.1	18.5	17	16.2	15.8	14.7
Ireland	31.9	32.1	32.4	32.4	32.2	31	31.2	34.4	28.4	28.5	28.9	28.8	28	27.4	27.3	27.1	26.5	25.8	24.8	24.5	23.8
Italy	31.9	26.6	26.4	25	24.9	25.1	24.1	24.1	24.3	23.8	22.4	23.1	22.6	22.6	22.9	24.5	24.1	23.8	23.9	23.8	23.8
Japan	33.4	33.9	33.6	32.3	32	30.6	29	28.1	29.2	28.3	26.8	25.7	25.7	23.5	24	21.8	20.8	20.7	20.1	19.8	19.6
Israel	36.3	35.4	34.7	33.9	32.8	31.7	31.2	30.7	29.8	29.3	28.6	28.2	27.7	27.2	26.6	26	25.8	25.2	24.4	23.8	23.4
Korea, Rep.	36.4	35.9	35.5	35.1	34.7	35	33.8	32.5	29.6	30.4	28.8	28.2	28	27.8	27.3	27.5	27.1	25.8	24.1	24.2	22.4
Netherlands	37.8	35.8	35.5	34.5	33.3	32.8	30.6	30.7	29.9	27.9	28.3	27.9	27.2	26.4	27	26	24.8	25.1	24.7	24.3	23.9
New Zealand	26.4	26.05	26.55	24.95	25.3	24.95	24.7	24.4	24.2	23.05	23.6	20.95	19.95	20.05	19.8	20.1	19.75	19.05	18.05	17.35	16.5
Norway	42.2	42.2	41.6	41	40.2	39.9	38.4	37.3	36.1	34.4	33.3	31.7	29.5	28.5	28.1	27.7	26.4	25.1	23.7	22.1	20.7
Poland	36.9	37.3	35.6	34.3	32.5	32.5	32.4	33.7	33.2	30.1	31.5	33.4	31	29.9	28.1	26.4	29	30.9	29.4	28.3	27.2
Portugal	25.4	24.5	23.5	22.9	23	22	21.9	21.7	21.4	21.3	21.3	20.8	22.7	22.3	21.2	20	21.3	21.9	21.6	21.6	22
Spain	38.8	37.2	37.2	35.9	36.4	35.7	34.8	34.4	33.9	34.1	33.2	32.4	32.8	32	30.1	31.9	31.5	30.9	30.7	30.3	29.7
Sweden	45.2	44.9	44.5	43.7	43.6	43.6	42.3	41.1	39.8	38.7	37.6	36.7	35.8	34.7	33.3	32.3	31.8	30.7	30.2	28.9	27.9
Switzerland	32.1	32.7	33.2	32.3	31. 5	30.2	29.7	29.5	28.7	27.8	27.3	26.3	26.2	26.4	26.7	26.9	26.7	26.4	26.3	26.1	25.9
United States	28.9	28.9	29.7	27.8	26.1	26.1	26.1	27.3	26.8	26.4	26.4	25.9	25.4	25.1	24.8	24.2	22	20	18.1	16.2	15.2
United Kingdom	32	30.6	30	29.8	28.8	29	28.7	28.2	27.5	26.2	25.5	24.1	23.1	22.4	21.6	20.8	20.5	19.5	18.9	18.3	18

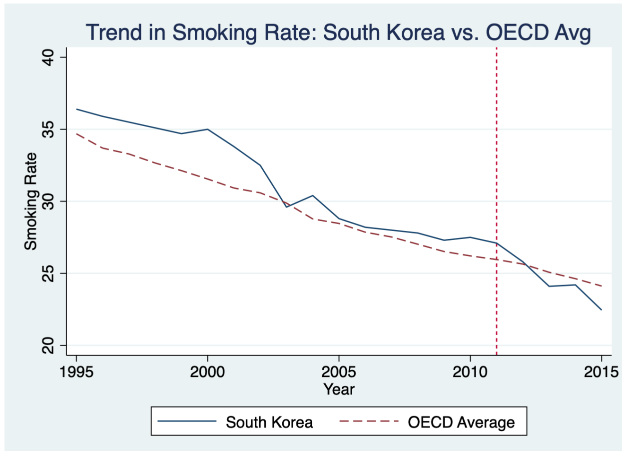
3.2 The Synthetic Control Method

The Difference-in-Differences (DiD) estimator is commonly used in comparative case studies. It uses the unit similar to the treated unit as a control representing the counterfactual of the treated unit as if there were no treatment. An estimate of the treatment effect is obtained by comparing the change in the outcome variable pre- and post-treatment, for the treated unit and the control. What makes the DiD estimator attractive for comparative studies is that, by taking time differences, it eliminates the influence of unobserved covariates that predict the outcome variable, assuming that the effects on the outcome variable are constant over time. A further assumption is that any macroeconomic shocks or other time effects are common to the treated unit and the control unit. These two assumptions are usually referred to as the "parallel trends assumption," implying in our case that, in the absence of the comprehensive SFP and outdoor smoking ban in South Korea, South Korea and the control unit follow parallel paths.

The parallel trends assumption is difficult to satisfy when the policies are implemented nationally at the same time since there is no control unit that is similar to the treated unit. This is the major concern for the DiD method in comparative case studies of nationally and simultaneously implemented policies. Also, the DiD estimator will be biased when the treated unit and the control unit do not follow a common trend. Figure 10 describes the trends in smoking prevalence in South Korea compared to the average of 27 OECD countries that are in the donor pool. Notice that the parallel trends assumption do not hold in the pre-treatment periods which means that the Difference-in-Differences method is not ideal in this case.

The synthetic control method (Abadie, 2021) could overcome such obstacles by namely, synthetically constructing the control unit from the convex combination of multiple units from the donor pool. The synthetic control method constructs the synthetic control unit to best match the pre-trend of the outcome variable and the choice of predictors. Thus, even if there is no single control unit, the parallel trends assumption is satisfied by its construction.

Figure 10: Path Plot of Smoking Prevalence During 1995-2015: South Korea Versus OECD Average of the 27 Donor Countries



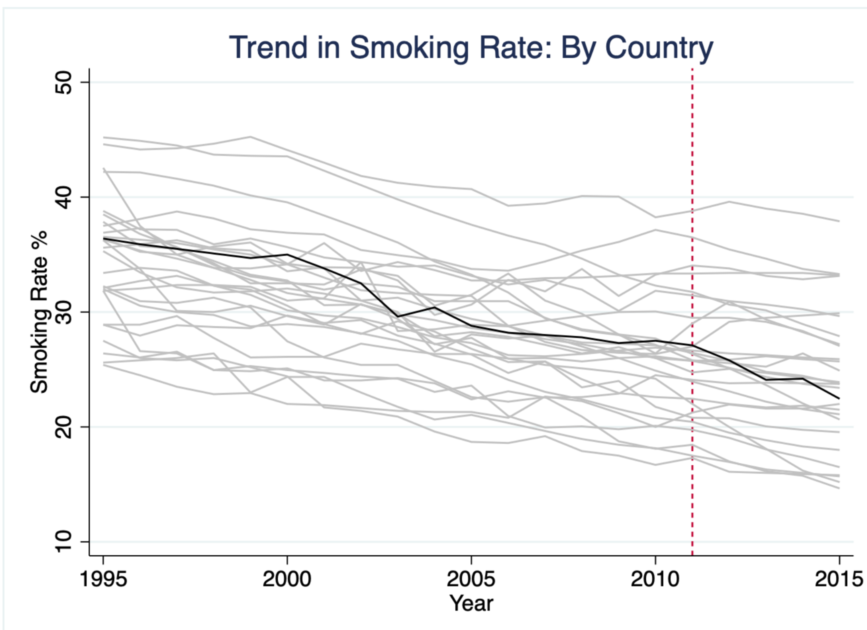
Note: 27 donor countries include Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, France, Finland, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Israel, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, the United States, and the United Kingdom.

More specifically, let $J+1$ be the number of OECD countries in my sample, indexed by j, and let $j=1$ denote South Korea, the treated unit. The units in the samples are observed for time periods $t=1,2,...,T$, and it is important to have data on a sufficient amount of time periods in pre-treatment as well as post-treatment to be able to construct a synthetic South Korea and evaluate the effect of the treatment. Synthetic South Korea is constructed as a weighted average of the control countries $j=2,...,J+1$ and represented by a vector of weights $W=(w_2,...,w_{J+1})'$ with $0 \leq w_j \leq 1$ and $w_2+...+w_{J+1}=1$ that minimizes the mean squared prediction error (MSPE) of a set of predictors and outcome variables over the pre-treatment period.

Since the synthetic control unit is constructed from the convex combination of multiple units from the donor pool and not allowing negative weights, it will be impossible to build the synthetic control unit when the treated unit is an outlier. However, I can rule out such case because the smoking rate trend in South Korea is not an outlier in our data set (see figure 11).

As key predictors, I use the log of GDP per capita, the proportion of the population aged 20-29, the proportion of agricultural, forestry, and fishery, and alcohol consumption per capita. Most of the predictors except the proportion of agricultural, forestry, and fishery were used in Abadie et al. (2010) which used the synthetic control methods to estimate the effect of California's tobacco control policy. I included the industrial size of agriculture, forestry, and fishery because people who work in these industries usually have high smoking rates and are less responsive to tobacco control policies. I average the four key predictors over the pre-treatment period, 1995-2010. Finally, to the list of predictors, I add three lagged years of the average smoking rates: 2000, 2006, and 2010.

Figure 11: Smoking Rates Trend by Country



Note: The solid line represents smoking prevalence for South Korea. The grey lines represent smoking prevalence in each country in the donor pool

4 Results

4.1 South Korea versus Synthetic South Korea

If Synthetic South Korea is able to track the smoking rates in real South Korea in the pre-treatment period and reproduce the values of the key predictors, it lends credibility to our identification assumption that the synthetic control unit provides the path of smoking rates from 2011 to 2015 in the absence of the the comprehensive SFP and outdoor smoking ban.

Figure 12 shows that, prior to treatment, smoking rates in South Korea and its synthetic counterpart track each other closely except for years between 2002 and 2005. Given that there was a rapid decrease in smoking rates because of the price shock in South Korea, it might be hard to find the exact match in these years and also closely track the smoking rates in the pre-treatment period. Further, because implementing tobacco control was the goal of WHO and a world trend, it is impossible to find a country that has not implemented any tobacco control policies in the post-treatment period. Thus, our estimate provides the effect of South Korea's specific sequences of tobacco control policies compared to its counterpart that implements some tobacco control policies rather than providing the effect compared to the absence of tobacco control policies. However, despite the downward bias of the estimate, the estimate obtained here is a more realistic measure since the absence of the comprehensive SFP and outdoor smoking ban does not mean the absence of any tobacco control policies; rather it may mean following the world trends.

Table 6 shows the descriptive statistics of South Korea and synthetic South Korea comparing the values of the key predictors in the pre-treatment period. For all predictors, except the proportion of the population aged 20-29, South Korea and its synthetic version have almost identical values. It supports our synthetic control unit reasonably tracks the real South Korea well, thus the synthetic control unit would provide good counterfactual in the post-treatment period.

The weights constructing the synthetic control unit are reported in table 7. It shows that the smoking rates in South Korea are best reproduced by a combination of Austria, the Czech Republic, Greece, Ireland, Iceland, and Israel. The rest of the countries in the donor pool received zero weight. The countries that received positive weights have a similar economic size as South Korea. The fact that all countries received similar weights in synthetic South Korea proves that it is difficult to find a single control unit for the counterpart of South Korea.

Table 6: Smoking Rates Predictor Means in Pre-Treatment Period

	Real South Korea	Synthetic South Korea
log GDP per Capita	9.84	10.16
Percent Aged 20-29	33.57	30.72
Industry: Agriculture & Forestry & Fishery	3.36	3.36
Alcohol Consumption per Capita	10.95	10.95
Smoking Rate 2000	35.00	34.09
Smoking Rate 2006	28.20	28.70
Smoking Rate 2010	27.50	27.22

Table 7: Country Weights in Synthetic South Korea

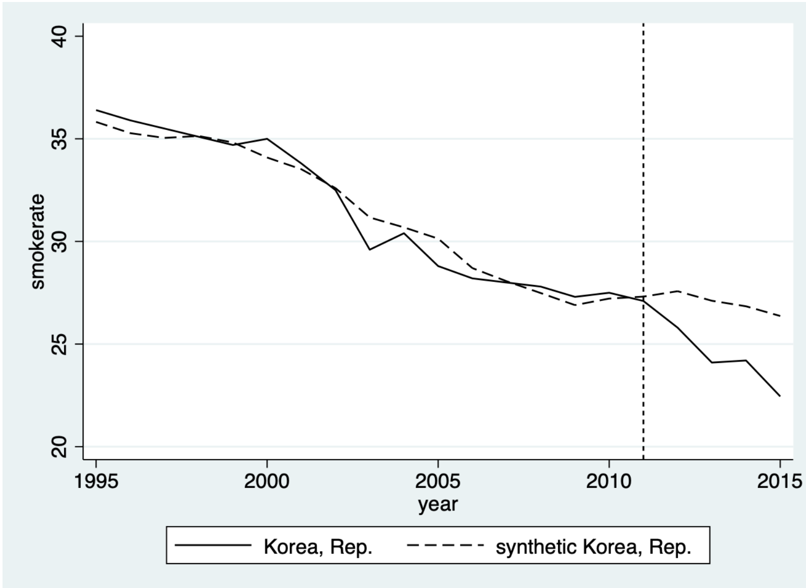
Country	Weight	Country	Weight
Australia	0	**Greece**	**0.16**
Austria	**0.10**	Hungary	0
Belgium	0	**Ireland**	**0.17**
Canada	0	**Iceland**	**0.17**
Switzerland	0	**Israel**	**0.12**
Czech Republic	**0.28**	Italy	0
Germany	0	Japan	0
Denmark	0	Netherlands	0
Spain	0	Norway	0
Estonia	0	New Zealand	0
Finland	0	Poland	0
France	0	Portugal	0
United Kingdom	0	Sweden	0
United States	0		

4.2 Smoking Prevalence Reductions

The average treatment effect is measured by the average of the post-treatment period's smoking rate distances between South Korea and Synthetic South Korea in figure 12. This distances is further visualized in the gap plot of figure 13. The introduction of the comprehensive SFP and outdoor smoking ban constantly reduced smoking prevalence over time from reduction of roughly 1.5 percentage points in the first year to roughly 4 percentage points in the fourth year of the implementation, despite a little increase in the third year. In the last year of the sample period, 2015, the average smoking rate in South Korea is 22.4%, or 4 percentage points lower than it would have been in the absence of the comprehensive SFP and outdoor smoking ban. From the smoking rate of 27.1% in 2011, the last year of the pre-treatment period, an estimated maximum smoking rate reduction of 4 percentage points is a 15%reduction. The average treatment effect of the smoke-free policies is calculated by taking the average of smoking prevalence reduction in post-periods. The average reduction is 2.3 percentage points, which is an 8.5% reduction from the baseline. In other words, the comprehensive SFP and outdoor smoking ban effectively prevented 1.2 million people from smoking, either by cessation of the current smokers or preventing the initiation of new smokers.

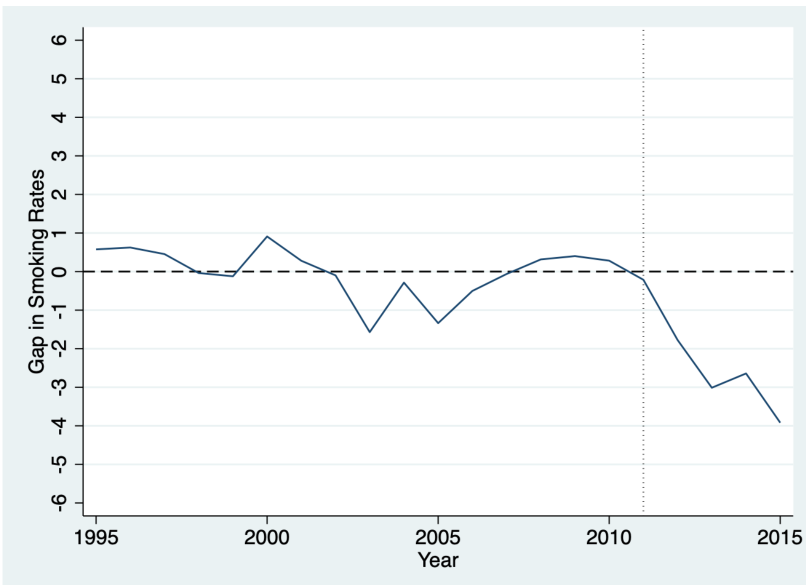
Levy and Friend (2001) reports that clean air laws may reduce cigarette consumption by 10-20% and also affect social norms in the long term which prevents initiation of smoking from new smokers. Although I do not have results for cigarette consumption, my study shows that smoking prevalence reduced by 8.5% on extensive margin.

Figure 12: Path Plot of Smoking Rates During 1995-2015: South Korea vs Synthetic South Korea



Note: This figure shows the path plot of smoking prevalence between 1995 and 2015. The solid line represents the smoking rates in South Korea based on the survey data of KNHANES. The dotted line represents the smoking rates in synthetic South Korea that had not implemented the comprehensive SFP and outdoor smoking ban in 2011.

Figure 13: Gap in Smoking Rates Between South Korea and Synthetic South Korea During 1995-2015



Note: This figure shows the smoking prevalence gap between actual South Korea and synthetic South Korea between 1995 and 2015. We can estimate the average treatment effect by calculating the average reduction in smoking prevalence during 2011-2015. The average treatment effect is -2.3117.

4.3 Placebo Tests

To further test the validity of the results, I performed both in-time and in-space placebo tests. For the in-time placebo test (see figure 14,15) the placebo policy is introduced in 2005, six year prior to actual policy changes, and in 2008, three year prior to actual policy changes. For the two tests, the choice of synthetic control is based only on data from 1995-2004 and 1995-2007, respectively. We want to find that this placebo treatment doesn't result in a post-placebo-treatment divergence in the trajectory of smoking prevalence between Korea and its synthetic control. A large placebo effect casts doubt on the claim that the result illustrated in figure 12 and 13 is the actual causal effect of the comprehensive SFP. Encouragingly, Figures 14 and 15 show no such divergence is found.

For the in-space placebo test, the treatment is iteratively reassigned to every country in the donor pool, again using the synthetic control method to construct synthetic counterparts. This gives us a method to establish if the result obtained for South Korea is unusually large, by comparing that result with the placebo results for all the countries in the donor pool. This form of permutation test allows for inference and the calculation of p-values: measuring the fraction of countries with results larger than or as large as the one obtained for the treated unit. Figure 16 shows the results of the in-space placebo test. Panel A indicates that for some countries in the donor pool, the synthetic control method is unable to find a convex combination of countries that will replicate the path of the average smoking rates in the pre-treatment period. I excluded the countries that have a root mean squared prediction error (RMSPE) larger than 1.25 for Panel B. The countries excluded are Australia, Austria, Belgium, Canada, Germany, Denmark, Spain, Finland, U.K., Greece, Ireland, Iceland, Italy, Japan, Netherlands, Norway, Poland, Portugal, Sweden, and U.S. Only 8 countries remained in the panel B. The gap in the average smoking rate in South Korea is the largest of all remaining countries. The p-value of estimating a gap of this magnitude is thus $1/28 = 0.036$.

Figure 14: The Placebo Treatment in 2005

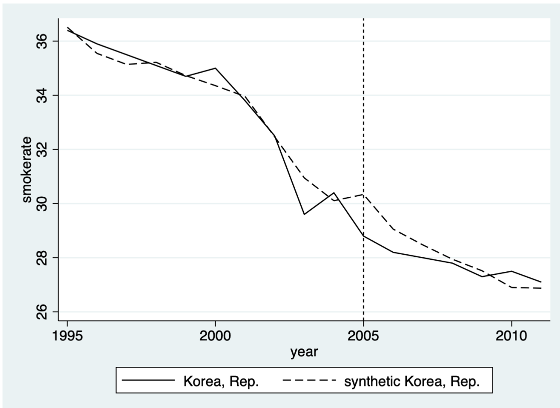
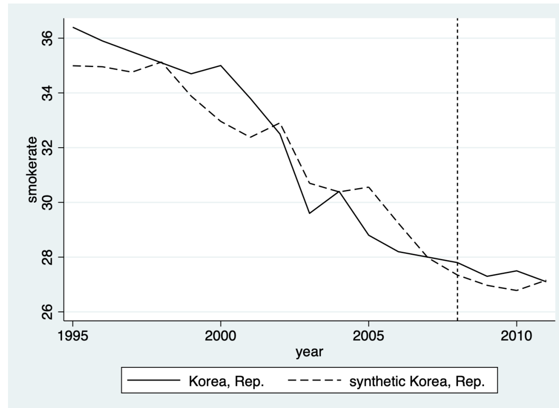
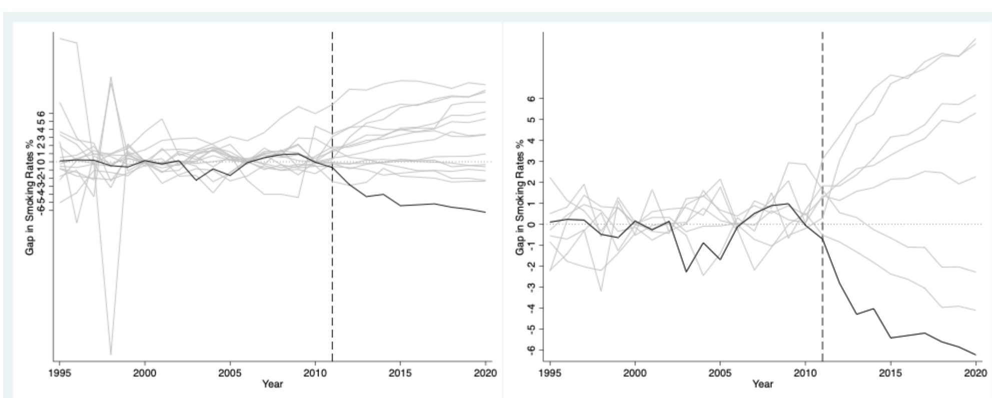


Figure 15: The Placebo Treatment in 2008



Note: Both figure shows an in-time placebo test. Left figure shows the path plot of smoking prevalence between real Korea and synthetic Korea when the placebo policy is introduced in 2005, six year prior to actual policy changes. Right figure shows when the placebo policy is introduced in 2008, three year prior to actual policy changes.

Figure 16: In-space Placebo Test: Smoking Rates Gap in South Korea and Placebo Gaps for the Control Countries



Note: Both figure shows an in-space placebo test, the treatment is iteratively reassigned to every country in the donor pool using a synthetic control method to construct synthetic counterparts. The left figure indicates that for some countries in the donor pool, the synthetic control method is unable to find a convex combination of countries that will replicate the path of smoking rates in the pre-treatment period. In the right figure, all the countries with a pre-treatment MSPE (mean squared prediction error) larger than 1.25 are excluded. The gap in smoking rates for South Korea in the post-treatment period is the largest of all remaining countries.

4.4 Augmented Synthetic Control Method

The recent literature on the Synthetic Control Method (SCM) has advanced the methodology to address the limitations of traditional SCM. One notable development is the Augmented Synthetic Control Method (ASCM), as introduced by Ben-Michael et al. (2021). Traditionally, SCM constructs a synthetic control unit by identifying non-negative weights that minimize the root mean squared error (RMSE) of the treated unit in the pre-treatment period. The key distinction between SCM and ASCM lies in ASCM's allowance for negative weights when synthesizing the control unit. ASCM employs a ridge regression model to estimate weights, which can be negative, thereby enabling arbitrary extrapolation. If the pre-treatment fit is accurate, the estimated bias will be minimal, making the SCM and ASCM estimates closely aligned. Figures 17 and 18 demonstrate the application of ASCM, showcasing results that closely mirror those obtained using traditional SCM.

4.5 Possible Confounder

As I discussed earlier, the control unit does not imply the absence of any tobacco control policies. Rather, it implies the absence of South Korea's comprehensive SFP and outdoor smoking ban which means that there are some tobacco control policies implemented in the control units. However, we can check the robustness of our estimates by studying the tobacco policies during the post-treatment periods in countries selected to construct the synthetic control unit. Details are in Appendix A.

5 Conclusion

In 2011, the South Korean government began rolling out intense tobacco control policies to reduce cigarette consumption and smoking prevalence, including the comprehensive SFP and outdoor smoking ban. This study uses the synthetic control method to estimate the effectiveness of the comprehensive SFP and outdoor smoking ban by looking at the reduction

Figure 17: Augmented Synthetic Control

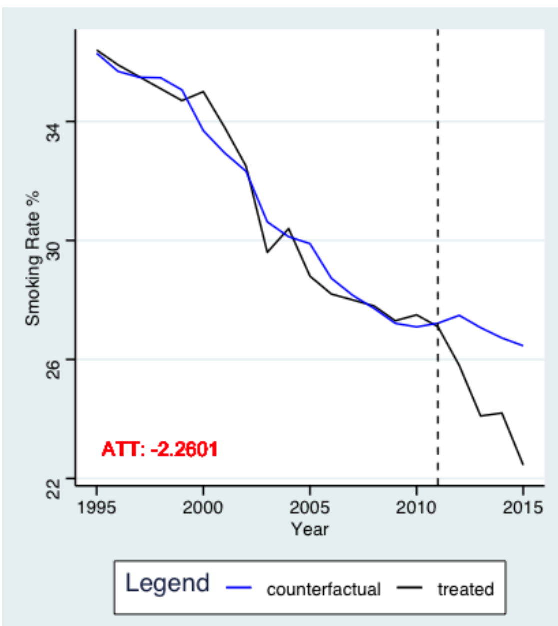
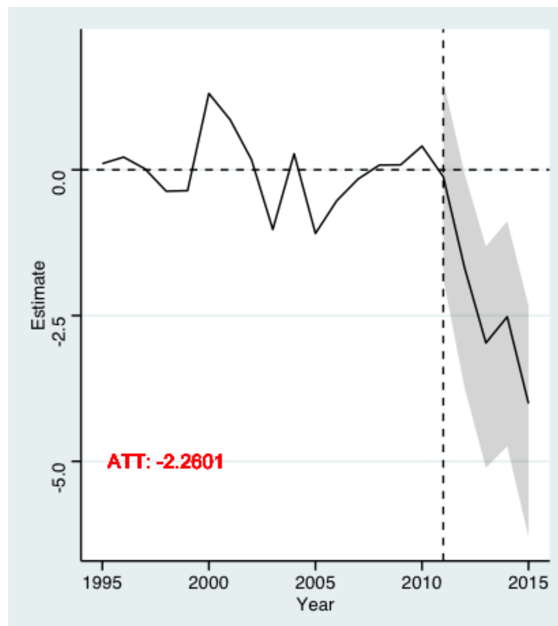


Figure 18: Augmented Synthetic Control



Note: Left panel shows the path plot of smoking prevalence between 1995 and 2015 using the augmented synthetic control method. The black line represents the smoking rates in South Korea based on the survey data of KNHANES. The blue line represents the smoking rates in synthetic South Korea that had not implemented the comprehensive SFP and outdoor smoking ban in 2011. The right panel shows the smoking prevalence gap between actual South Korea and synthetic South Korea between 1995 and 2015 using the augmented synthetic control method. We can estimate the average treatment effect by calculating the average reduction in smoking prevalence during 2011-2015. The average treatment effect is -2.2601.

of the average smoking rates compared to the synthetic control unit in the post-treatment period. I can conclude that the comprehensive SFP and outdoor smoking ban significantly reduced the smoking prevalence by 2.3 percentage points on average from the average smoking rate of 27.1% in 2011, which is an 8.5% reduction. In other words, the comprehensive SFP and outdoor smoking ban effectively prevented 1.2 million people from smoking, either by cessation of the current smokers or preventing the initiation of new smokers.

South Korean government introduced comprehensive smoke-free policy (SFP) and outdoor smoking ban in 2011. These policies mandated a complete smoking ban in public transport, government buildings, medical care facilities, nurseries, schools, large restaurants and bars, as well as large buildings and theaters. Smoking was only permitted in designated smoking rooms that were completely isolated from other spaces; violators faced monetary fines. Before this, the South Korean government had not changed their policy pertaining to indoor smoking since designated establishments were required to divide smoking and non-smoking sections in 1995. The comprehensive SFP was gradually extended to include all restaurants and cafes, starting with those larger than 150 square meters in 2013, places larger than 100 square meters in the following year, and eventually encompassing all restaurants and cafes in 2015.

Several studies have used pre-post analysis to show that comprehensive SFP in South Korea is associated with improved indoor air quality (Kim et al., 2016) and reduced secondhand smoke exposure (Park et al., 2020); however, these studies could lead to a biased estimate of the causal effect of the policy due to uncontrolled nation-specific, time-varying heterogeneity. To study this question plausibly causally, I construct the country-level panel data using data from International Smoking Statistics (ISS), Korean National Health and Nutrition Examination Survey (KNHANES), World Health Organization (WHO) tobacco use data, and World Development Indicators (WDI) data. My study is the first to use a synthetic control group approach, by constructing a hypothetical South Korea without implementation of the comprehensive SFP and outdoor smoking ban by using the panel data from 28 other high-income countries without adopting extensive smoke-free laws from 2011 to 2015. By comparing the real South Korea with this synthetic counterpart, we can measure the average treatment effect of the policy.

The synthetic control group results indicate that the comprehensive SFP and outdoor smoking ban effectively reduced smoking prevalence by an average of 2.3 percentage points from the 27.1% smoking rate in 2011 ($p < 0.036$). This represents an 8.5 percent reduction when compared to a scenario without the policy. In practical terms, the the comprehensive SFP and outdoor smoking ban deterred approximately 1.2 million people from smoking, either through encouraging current smokers to quit or preventing the initiation of new smokers.

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A Tobacco Control Policies and Cigarette Prices in Countries Selected for Synthetic Korea

Austria (0.10)

- 1995: Federal Tobacco Act passed
- 2005: Signed WHO FCTC
- 2008: Expansion on No Smoking signs
- 2016: Mandate on pictorial warning labels
- 2019: Total ban on smoking at bars and restaurants

Czech Republic (0.28)

- 1995: Advertisement regulation on tobacco
- 2003: Mandate on text warning labels
- 2005: Smoke-free zone on schools, medical facilities, and public areas
- 2012: Signed WHO FCTC
- 2016: Mandate on pictorial warning labels

Greece (0.16)

- 2003: Advertisement regulation on tobacco
- 2006: Signed WHO FCTC
- 2009: Smoke-free zone on schools, healthcare facilities, indoor working spaces, and public areas
- 2016: Mandate on pictorial warning labels

Ireland (0.17)

- 2004: Smoke-free zone on schools, healthcare facilities, indoor working spaces, public areas, restaurants, and bars
- 2005: Signed WHO FCTC
- 2016: Mandate on pictorial warning labels

Iceland (0.17)

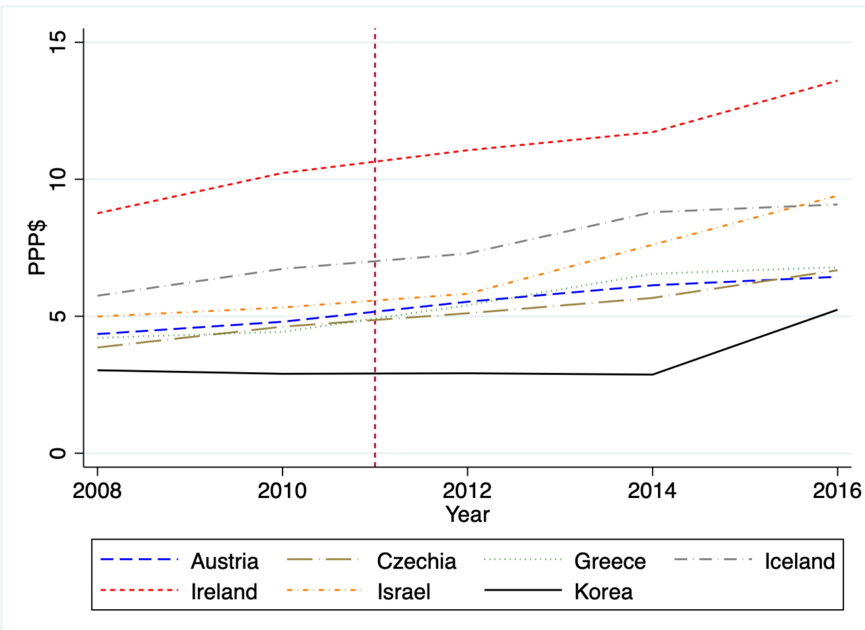
- 2002: Smoke-free zone on schools, healthcare facilities, indoor public gatherings
- 2003: Mandate on text warning labels
- 2005: Signed WHO FCTC
- 2007: Smoke-free zone in public areas and businesses
- 2016: Mandate on pictorial warning labels

Israel (0.12)

- 1983: National tobacco control began, no smoking in public spaces
- 2002: Mandate on text warning labels
- 2005: Signed WHO FCTC
- 2012: Smoke-free zone in schools and hospitals

Cigarette Prices

Figure 19: Changes in Cigarette Prices for South Korea and the Countries Included in Synthetic South Korea



Note: The cigarette price is the lowest among the countries that construct the synthetic Korea. All of the countries included in the synthetic Korea increased the cigarette price during 2011-2015 which may contribute to the reduction of smoking prevalence in the synthetic Korea that will bias the results toward less average treatment effect. The average treatment effect estimated from the synthetic control method will be the lower bound of the actual average treatment effect.