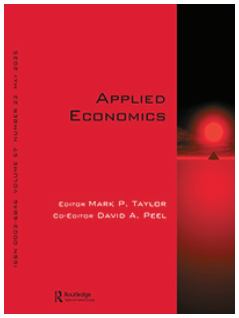

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To heat or burn? Evidence from heated tobacco product adoption in South Korea

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ABSTRACT

This paper examines the determinants that induce smokers to switch from conventional cigarettes to heated tobacco products (HTPs). To this end, we collected survey data for Korean adults consisting of 2,356 non-smokers, 1,316 conventional cigarette smokers, and 842 HTP smokers. By employing a bivariate Probit model with sample selection, we estimated the sequential decision process of product choice, whether to smoke, and which tobacco product to choose if they smoked. Our results showed that those who were young, female, and more educated and had under-age children, indoor occupations, and higher health concerns were more likely to switch to HTPs. Furthermore, the incentive to switch to HTPs from conventional cigarettes is aligned with the incentive to quit smoking or become non-smokers. In contrast, we found no evidence that HTPs serve as a gateway for the initiation of smoking. These results suggest that HTPs can play a role in bridging smoking regulations, and that policymakers need to consider their role in designing taxation and health policies.

KEYWORDS

Heated tobacco products (HTPs); sample selection model; tobacco product choice; tobacco policy

JEL CLASSIFICATION

I12; I18; J13

I. Introduction

Recent technological progress in tobacco markets has brought us a novel tobacco product, called Heated Tobacco Products (hereafter, HTPs) such as IQOS, Ploom, and Glo. The new products have appealed to smokers with the features characterized by the similarity of smoking satisfaction with conventional cigarettes, but with less odour.[1] For this reason, HTPs have surpassed e-cigarettes and have become the most conspicuous alternative for conventional cigarettes in Korea.[2]

The launch of HTPs in Korean tobacco market has led to dynamic changes. Figure 1 clearly shows that sales volume of HTPs has remarkably increased while displacing conventional cigarettes since IQOS was first introduced in Korea in May 2017.[3] HTP accounts for only 2.2% of the total tobacco sales in the first year of its launch and accounts for 12.0% in the first half of 2021. These dramatic changes in the Korean tobacco market provide us with an excellent research environment to investigate what makes smokers adopt HTPs so rapidly, which is of particular interest to policy makers in terms of tobacco regulatory system including taxation and market regulation.

This paper examines the determinants that induce smokers to switch to HTPs from conventional cigarettes. To do so, we collected survey data, consisting of 4,514 Korean adults, of which smokers are 2,158 and non-smokers are 2,356. Because we focus on tobacco product choices of smokers, the survey was designed to ensure that smoker respondents belong to either HTP smokers or

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[1]In 2020, the Korean National Health and Nutrition Examination Survey, a representative public statistics on health issues in Korea, asked HTP smokers for the reasons for adopting HTPs. According to the survey, 46.7% of HTP smoker respondent chose 'because HTPs have less odour', with 19.2% answering 'because HTPs are less harmful', and with 15.0% responding 'because HTPs are helpful to quit smoking'. These results indicate that individuals' socio-demographic characteristics associated with the features of HTPs can play an important role in the decision on HTP adoption.

[2]HTPs and e-cigarettes are similar in that both use an electronic device to generate aerosols inhaled by smokers. However, there are significant differences between the two: HTPs heat real tobacco within a specific temperature range without burning, whereas e-cigarettes vaporize an e-liquid solution containing nicotine and flavours. One key advantage of HTPs is that their heating system allows smokers to experience a taste more similar to conventional cigarettes. This can make HTPs a more attractive alternative to smokers who are willing to switch from conventional cigarettes but still adhere to a similar taste experience, thereby allowing HTPs to become more popular in Korea compared to e-cigarettes.

[3]As a recent study by Golpe et al. (2022) pointed out, Phillip Morris International (PMI) has aggressively penetrated the global HTP market with IQOS while inducing conventional cigarette smokers to switch to HTPs by providing tax incentives. Likewise, PMI was a leading provider in the HTP market during the early stage of HTP introduction in Korea. However, the HTP market has become more competitive in Korea as other major tobacco manufacturers such as KT&G, BAT, and JTI have entered the market. In fact, according to Nielsen's sales data, PMI accounted for 96.3% of HTP sales in 2017, but four years later, in 2021, its market share plummeted to 52.6%. Meanwhile, the market shares of other HTP manufacturers have increased in 2021, with KT&G accounting for 38.3% and BAT accounting for 9.1%.

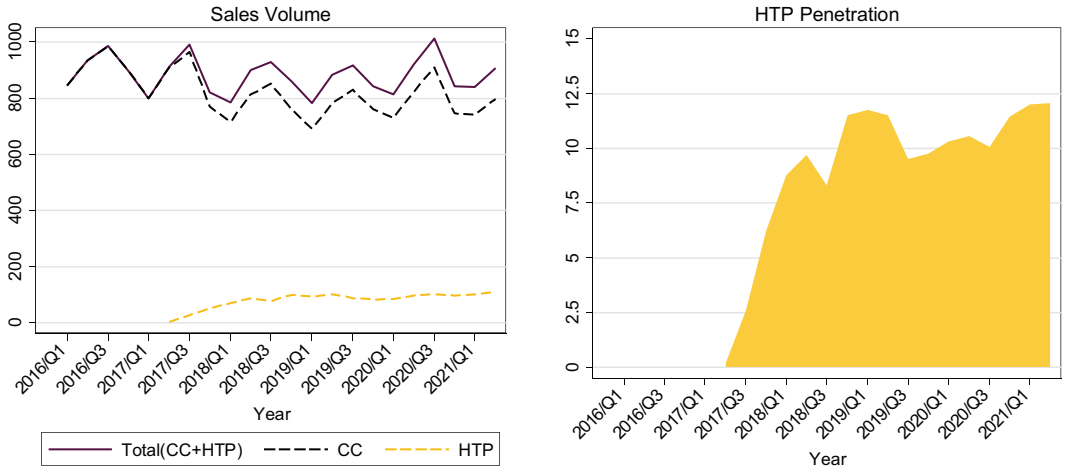

Figure 1. Quarterly sales volumes and penetration rate of HTPs. CC and HTP stand for conventional cigarettes and heated tobacco products, respectively.

conventional cigarette smokers, depending on the tobacco products they consume the most. As the determinants of tobacco product choice, we gathered information regarding smoking history, health, and socio-demographic variables in line with existing literature (Clark and Etilé 2002; Jones 1994; Lahiri and Song 2000; Yen and Jones 1996).

For the estimation, we paid attention to the fact that individuals follow sequential steps to select their tobacco product, i.e. whether to smoke and which tobacco product to choose if they smoke. To account for the sequential decision process of both smokers and non-smokers, we employ a bivariate Probit model with sample selection developed by Van de Ven and Van Praag (1981). This method helps us correct for the sample selection bias that would have occurred when using only the smoker sample in the estimation.

Our findings can be summarized as follows: First, our results suggest that health concerns and socio-demographic characteristics play an important role in explaining smokers' switching behaviour to HTPs from conventional cigarettes. The smokers were more likely to switch to HTPs if they were young, were female, were more educated, had under-age children, had indoor occupations, and had higher health concerns. Second, the incentive to switch to HTPs from conventional cigarettes is very similar to the incentives to quit smoking or become a non-smoker. For instance, those who are relatively sensitive to health risk or tobacco odour are more likely to be non-smokers or choose HTPs if they smoke. This gives us clues as to how we can exploit HTPs as a part of smoking cessation policies.

Third, we also find that those who start smoking during adolescence are less likely to choose HTPs, and rather stick to enjoying conventional cigarettes. This result indicates that it is very unlikely that HTPs serve as a gateway to start smoking, contrary to serious concerns by Czoli et al. (2020) and McKelvey et al. (2018). Finally, our results show that the incentives to adopt HTPs vary widely with age cohort. Among young adults aged 20–39 years, they were more likely to switch to HTPs if they are female, and choose HTPs regardless of individual income. In contrast, those who aged over 40 were more likely to switch to HTPs if they were male and earned more income. We believe that this heterogeneity across age groups occurred because HTPs appeal to young adults as a new technology.

Previous literature has strived to explain the demand for cigarettes theoretically, taking into account addictive behaviours of smoking (Becker and Murphy 1988; Becker, Grossman, and Murphy 1991; Spinnewyn 1981), and numerous empirical studies have explored the determinants of smoking demand and price elasticity from the demand estimation (see Chaloupka and Warner (2000)). By doing so, they offered several policy implications

such as excise taxes, indoor restrictions, and advertising regulations to control tobacco consumption (Álvarez et al. 2020; Baltagi and Levin 1986; Buonanno and Ranzani 2013; Levy, Chaloupka, and Gitchell 2004; Saffer and Chaloupka 2000; Sobel and Garrett 1997; Tauras 2004; Thrasher et al. 2011). The interest in demand for cigarette consumption has expanded to explain the general smoking decisions from smoking initiation to smoking cessation. For example, Lahiri and Song (2000), Yen (2005), and Yen and Jones (1996) found evidence that health conditions and socio-demographics such as education, age, and occupation play an important role in smoking decisions.

With the growing variety of tobacco products due to the recent technological progress in the tobacco markets, more recent studies (Delnevo et al. 2016; Laverty, Filippos, and Vardavas 2018; Park et al. 2017; Simonavicius et al. 2020; Vallone et al. 2020) have explored smokers' decision on e-cigarette uses. These studies have focused the effects of socio-demographic factors and smoking status on e-cigarette use. In general, they found that those who are male, younger, non-Hispanic White, highly educated, and current users of conventional cigarettes are more likely to smoke e-cigarettes. Interestingly, Delnevo et al. (2016) and Laverty, Filippos, and Vardavas (2018) reported that young adults or adolescent tend to be more likely to try the new tobacco product, but those who are more likely to use e-cigarettes regularly once they have adopted are older smokers. Park et al. (2017), similar to our study in terms of the topic focusing on switching behaviours of smokers, divided the smoker groups into three: smokers who switched to e-cigarettes from conventional cigarettes, dual users, and former smokers who quit without switching. They found that those who are young are more likely to switch to e-cigarettes compared to former smokers, whereas those who are more educated and married are more likely to switch to e-cigarettes compared to dual users.

However, relatively less attention has been paid to smokers' behaviours on HTP adoption. We believe that this is because the penetration of HTPs was not as prevalent in other countries as in Korea. Nonetheless, a few studies on HTPs have examined the concurrent uses of tobacco products including HTPs (Dunbar et al. 2020; Hwang, Ryu, and Park 2019; Kim et al. 2018; Wu et al. 2020) or the relationship between adolescence smoking and HTPs (Dai 2020; Kang and Cho 2020). The former found that concurrent smokers were more likely to be aware of or use HTPs. Similarly, the latter provided evidence that poly-tobacco uses are prevalent in youth. Furthermore, Dunbar et al. (2020), Hwang, Ryu, and Park (2019), and Kang and Cho (2020) suggest that HTPs are not correlated with the smoking cessation or the attempt to quit. Although these studies provide interesting results regarding the consumption pattern of smokers by comparing the uses of different types of tobaccos, they did not investigate the reason why smokers choose a specific tobacco product or switch to HTPs. In this paper, we strive to fill this gap in the literature.

Interestingly, recent studies by Martín-Álvarez et al. (2023) and Kinjo et al. (2020) suggest that consumers' perception that HTPs are less harmful has played a key role in the recent prevalence of HTPs. Martín-Álvarez et al. (2023) demonstrated that the adoption of HTPs has a similar consumption pattern as other products considered 'heathy', such as additive-free or ultra-slim cigarette brands. Kinjo et al. (2020) showed that the prevalence of HTPs is related to socio-demographic profiles. They both highlight the implicit linkage between the adoption of HTPs and socio-demographic profiles related to preferences for the consumption of the healthy brands. Our study is also aligned with these studies in that we investigated the determinants that influence smokers' choice between conventional cigarettes and HTPs by relating socio-demographic characteristics with the switching behaviour of HTPs.

This paper contributes to the literature in two aspects. First, we shed light on the role of HTPs in tobacco regulation policy. Our empirical findings provide evidence that there is no positive relationship between smoking in adolescence and HTP use, and that the incentives for HTP adoption are similar to those for smoking cessation in terms of health concerns and socio-demographic factors. Moreover, we show that the heterogeneity across age groups has significant effects, especially on HTP adoption. We believe that all these results can provide important implications for policymakers when designing smoking control policies such as smoking cessation and age targeting programs.

Second, the paper improves methodological rigour in estimating the determinants of tobacco

product choices. We applied the bivariate Probit model with sample selection, which estimates the sequential decision process of tobacco products (i.e. whether to smoke and which tobacco product to choose if smoked) in one model while adjusting the sample selection bias. In terms of the estimation method, Jones (1994) is comparable to our study. He examined the sequential smoking cessation considering the decision to quit smoking and the success in quitting. On the contrary, we applied the same method to investigate the sequential decision process on tobacco product choices. Our results suggest that correcting the selection bias would be necessary when estimating the probability of tobacco product choices.

This paper is organized as follows: In section II, we explain the survey data and its descriptive statistics. Section III explains the empirical strategy and the sample selection model we used. Section IV reports our empirical results and discusses their implications. Finally, we conclude with some policy implications in section V.

II. Data and descriptive statistics

We collected survey data from both smokers and non-smokers in May 2020, conducted by Korea Data Network, one of the leading survey companies in Korea. We identified smokers and non-smokers according to their current smoking status. Further, current smokers were classified as conventional cigarettes and HTP smokers depending on the tobacco products they consume the most.[4] Other tobacco products, such as e-cigarettes, were excluded from our sample because their sales volumes are negligibly small in Korean tobacco market.[5] In addition, despite the presence of dual users (e.g. those who smoke conventional cigarettes and HTPs) in the real world, the survey was intentionally designed to ensure that smoker respondents belong to either conventional cigarette smokers or HTP smokers. By doing so, we are able to identify smokers' decision on switching from one product to the other.

Owing to data limitation, we assumed in this study that all current HTP smokers had previously smoked conventional cigarettes before adopting HTPs. This assumption allows us to draw general inferences regarding HTP smokers' switching behaviour.[6] Indeed, 90.4% of HTP smokers in our sample responded that they began smoking before HTPs were introduced, indicating that the majority of current HTP smokers switched from conventional cigarettes. Furthermore, the Korea National Health and Nutrition Examination Survey (KNHANES) – a national public survey conducted by the Korea Disease Control and Prevention Agency – provided evidence to support that our assumption is not overly strong. The latest KNHANES data from 2021 reveal that 99.4% of all HTP smokers currently adopting HTPs either switched from conventional cigarettes or are dual users, whereas only 0.6% were purely new HTP smokers who had never smoked before. Nonetheless, there may still exist an issue that our results might be misleading because some of the HTP smokers in our sample have not switched from conventional cigarettes but have taken up smoking with HTPs. To alleviate this concern, we repeated our main analysis after removing from the sample HTP smoker respondents who took up smoking after HTPs were introduced, and the results were qualitatively the same as those of the main analysis.[7] Hence, we included all current HTP smokers in our main analysis, not only to reflect the characteristics of all age groups in the regression analysis but also to address the sample selection issue.[8]

The data consist of 4,514 adults (aged 19 and over), of which smokers are 2,158 and non-

[4]The survey asked current smokers to select one out of 'conventional cigarette', 'HTP', 'e-cigarette', and 'others' to the question '*which tobacco products do you mainly consume?*'.

[5]According to the public statistics from Ministry of Economy and Finance, conventional cigarettes, HTPs, and other tobacco products account for about 89.40%, 10.56%, and 0.04% of total sales volume in 2020, respectively.

[6]In a strict sense, our study investigated the determinants of HTP adoption but did not directly examine dynamic switching behaviours from conventional cigarettes to HTPs. However, if almost all HTP smokers switched from conventional cigarettes, it would be natural to think that HTP adoption could reflect switching behaviour. As discussed in this section, our data and public statistics confirmed that almost all HTP adoption indeed occurred because of switching from conventional cigarettes. In this sense, we believe that our static model estimating the determinants of HTP adoption would be sufficient to draw inferences regarding HTP smokers' switching behaviours by treating the *ex post* decision on HTP adoption as switching behaviours.

[7]For brevity, the empirical results are not presented in the main text. However, it can be obtained from the authors upon request.

[8]It is naturally expected that those who started smoking since 2017 (the year HTPs were introduced) are very likely to be young. Therefore, removing them from our sample hinders us from identifying the determinants of switching behaviours of younger generations, resulting in sample selection bias.

smokers are 2,356. Of the smokers, 842 respondents were HTP smokers while 1,316 were conventional cigarette smokers. Because we are interested in uncovering the driving factors that induce smokers to switch from conventional cigarettes to HTPs, it is important to obtain sufficient observations for each group. For this reason, we oversampled smokers compared to non-smokers, and HTP smokers compared to conventional cigarette smokers.

We gathered information on smoking history, health variables, and socio-demographic characteristics from survey respondents. First, we use smoking history variables such as age of smoking initiation, relative smoking duration, and amount of cigarette consumption per week to examine the effects of nicotine dependence on smokers' decisions.[9] Initiation age was separated into four intervals of '$\leq$15', '15–18', '19–24', and '$\geq$25' to consider how smoking in adolescents affects tobacco choice. Relative smoking duration is defined as smoking duration divided by age. Regarding health variables, respondents were asked about their health-related activities, subjective health confidence (1 = low to 5 = high), family health history, and whether they currently have diseases. As socio-demographic variables, we consider age, gender, educational attainment, occupation, individual income, house ownership, residential area, and whether to live with children under 18 or adult children. Occupations are classified as self-employed/farmer, laborer/technician/engineer, sales/service, management/professional, office worker, and unemployed.

Table 1 describes the summary statistics for the variables of interest by smoking types. Comparisons between HTP and conventional cigarette smokers show that they have quite different characteristics. HTP smokers engage in more health activities and have higher self-confidence in health. Moreover, they are more likely to be female, be more educated, earn more income, own a house, have indoor occupation, and live with children. Indeed, the last column of Table 1, which shows the mean differences between HTP and conventional cigarette smokers, confirms that most socio-economic characteristics are statistically significantly different from each other. This implies that health and socio-demographic differences may explain tobacco product choice of smokers. We also find that non-smokers have very different characteristics from smokers. Especially, it can be seen that non-smokers are exposed to more health risks in terms of their family health history and their own diseases than smokers. In addition, it is noticeable that non-smokers consist more of those who are unemployed and females, and thereby earn relatively low incomes.

In Table 2, we compare the distribution of health and income variables based on age cohort and smoking types. From the results, we can find that HTP and conventional cigarette smokers have very different distributional features across age groups, especially in terms of health activities and incomes. For the smoker groups aged 20–39, it seems that their distributions are quite similar. However, it can be clearly seen that within the smoker groups aged over 40, HTP smokers engage in more health activities and earn higher income than conventional cigarette smokers. This shows that the motivation to switch to HTPs from conventional cigarettes can differ between younger and older generations, thus implying that our estimation should be able to consider heterogeneous age effects on tobacco product choices of smokers.

III. Empirical strategy

In this paper, we empirically investigate the determinants that affect smoker's choice between conventional cigarettes and HTPs. Several previous studies (e.g. Park et al. 2017; Simonavicius et al. 2020) in this literature have applied the multinomial logit model to estimate the probability of smokers' choice among alternative tobacco products, typically restricting their sample only to the smoker group. Consequently, these studies did not consider the existence of an outside option of 'not to smoke'. In this case, these estimates might be misleading if a serious selection problem occurs in their estimation as they ignore non-smokers' decision. For example, suppose that individuals with high health concerns become non-smokers. Then,

[9]For those who answered current smokers, we collected their smoking initiation age, the amount of daily cigarette consumption, and frequency of smoking per week. Using the information, we calculated the cigarettes smoked per week.

Table 1. Summary statistics.

	Non-smoker		HTP		Conventional Cigarette (CC)		
	Mean	Std.dev	Mean	Std.dev	Mean	Std.dev	Diff. (HTP-CC)
Smoking History							
Age of smoking initiation			21.48	4.11	21.13	4.51	0.36*
cigarettes smoked per week			54.00	47.57	61.81	54.45	−7.81***
Relative smoking duration			0.39	0.16	0.40	0.16	−0.01
Health var.							
Activities for health							
Regular Exercise	0.37	0.48	0.35	0.48	0.33	0.47	0.03
Diet therapy	0.15	0.36	0.20	0.40	0.16	0.37	0.04**
Others(supplements, medical check-up)	0.33	0.47	0.33	0.47	0.35	0.48	−0.02
No activities	0.15	0.36	0.12	0.33	0.16	0.37	−0.04***
Health confidence							
Very low	0.07	0.26	0.05	0.23	0.09	0.28	−0.03***
Low	0.37	0.48	0.36	0.48	0.40	0.49	−0.04*
Medium	0.35	0.48	0.41	0.49	0.37	0.48	0.05**
High	0.18	0.39	0.14	0.35	0.13	0.33	0.01
Very high	0.03	0.17	0.03	0.17	0.02	0.13	0.01*
Family health history							
No diseases within 4th-degree relatives	0.61	0.49	0.75	0.44	0.74	0.44	0.01
Any diseases for 4th-degree relatives	0.12	0.33	0.10	0.30	0.10	0.30	0.01
One disease for 1st-degree relatives	0.18	0.39	0.11	0.31	0.11	0.31	0.0003
Two or more diseases for 1st-degree relatives	0.09	0.28	0.04	0.20	0.05	0.22	−0.01
Disease	0.07	0.26	0.05	0.22	0.06	0.23	−0.01
Sociodemographic var.							
Age	36.38	10.26	37.10	9.23	37.07	10.04	0.04
Female	0.65	0.48	0.39	0.49	0.33	0.47	0.07***
Occupation							
Self-employed, Farmer	0.05	0.22	0.07	0.26	0.10	0.31	−0.03***
Laborer, Technician/Engineer	0.07	0.25	0.13	0.34	0.16	0.36	−0.02
Sales/Service	0.09	0.28	0.11	0.32	0.12	0.33	−0.01
Management, Professional	0.08	0.27	0.10	0.30	0.08	0.27	0.02*
Student	0.08	0.26	0.06	0.23	0.07	0.25	−0.01
Office worker	0.41	0.49	0.45	0.50	0.38	0.49	0.06***
Unemployed(includes homemaker, retired)	0.22	0.42	0.09	0.28	0.09	0.29	−0.005
Education							
High school diploma or less	0.19	0.39	0.19	0.39	0.24	0.43	−0.05***
College degree	0.20	0.40	0.22	0.41	0.25	0.43	−0.03
Bachelor degree	0.54	0.50	0.53	0.50	0.47	0.50	0.06***
Master degree or higher	0.07	0.26	0.06	0.25	0.05	0.21	0.02*
living with children aged under 18	0.24	0.43	0.28	0.45	0.23	0.42	0.05***
living with adult children	0.07	0.26	0.04	0.20	0.06	0.23	−0.02*
Individual income (1,000 KRW)							
<24,000	0.39	0.49	0.23	0.42	0.26	0.44	−0.03
24,000–3,599	0.31	0.46	0.30	0.46	0.32	0.47	−0.01
36,000–59,999	0.23	0.42	0.36	0.48	0.35	0.48	0.01
≥60,000	0.06	0.24	0.11	0.31	0.08	0.27	0.03**
Home ownership	0.38	0.49	0.45	0.50	0.40	0.49	0.06***
Observations	2,356		842		1,316		

if we use only smoker data for the estimation, the effects of health concerns on tobacco product choices would be underestimated because all smokers have relatively low health concerns. Therefore, it is important to carefully deal with these selection problems in our context.

To alleviate the selection problem, we adopt a bivariate Probit model with sample selection for estimating the switching probability of smokers to HTPs. In particular, we notice that individuals need to decide not only whether or not to smoke but also which tobacco products to choose if they do. The sample selection model allows us to fully consider this sequential decision process as follows: In the first stage, the probability that individuals choose to smoke is estimated by using both smoker and non-smoker sample. In the next stage, we estimate the switching probability of smokers to HTPs by using smoker sample only. Wherein, the probability of smoking choice obtained in the first stage is used to correct the selection bias. In this way, the bivariate Probit model with sample selection can explicitly incorporate both smoking and tobacco product decisions into one estimation model.

Heckman (1979) suggests the two-stage sample selection model with a continuous dependent

Table 2. Health and income statistics by age cohort.

	HTP user				CC user			
age	20s	30s	40s	50s-	20s	30s	40s	50s-
Activities for health								
Regular Exercise	36.0	30.6	34.5	51.6	38.0	32.2	27.7	31.5
Diet therapy	14.7	22.3	23.0	16.5	13.0	14.0	24.7	9.5
Others(supplements, medical check-up)	30.8	35.0	34.5	25.3	29.6	38.5	33.6	40.5
No activities	18.5	12.1	8.0	6.6	19.4	15.3	14.0	18.5
Health confidence								
Very low	4.7	3.2	8.0	8.8	5.6	9.0	9.5	12.5
Low	28.4	40.8	34.5	42.9	32.1	39.8	48.8	39.3
Medium	40.8	41.4	43.8	37.4	40.6	38.5	33.0	32.7
High	19.9	12.7	11.9	9.9	18.9	11.8	7.4	13.1
Very high	6.2	1.9	1.8	1.1	2.8	0.9	1.2	2.4
Family health history								
No diseases within 4th-degree relatives	82.5	74.8	68.6	70.3	76.9	78.3	70.2	62.5
Any diseases for 4th-degree relatives	5.2	13.1	9.7	14.3	10.4	9.0	8.6	13.1
One disease for 1st-degree relatives	8.5	9.6	15.5	11.0	9.0	8.3	13.1	18.5
Two or more diseases for 1st-degree relatives	3.8	2.5	6.2	4.4	3.7	4.4	8.0	6.0
Disease	3.3	2.9	4.4	18.7	3.4	2.4	7.7	16.1
Individual income (1,000 KRW)								
$<$ 24,000	33.6	24.2	12.4	17.6	38.6	17.7	19.9	30.4
24,000–3,599	46.0	29.9	19.0	24.2	42.0	35.9	23.2	14.9
36,000–59,999	18.0	38.5	50.0	33.0	17.5	40.0	44.9	36.3
$\geq$60,000	2.4	7.3	18.6	25.3	2.0	6.3	11.9	18.5

variable to correct the selection bias. However, this method is not applicable in our case because we are interested in the discrete choice of tobacco products. Thus, we applied a bivariate Probit model with sample selection, developed by Van de Ven and Van Praag (1981) and widely used in several empirical studies (Jones 1994; Kaplan and Venezky 1994).

To be specific, the selection equation is defined as follows:

$$s_i = 1(Z_i\gamma + \eta_i > 0)$$

s_i equals one if individual i is a smoker, 0 otherwise. Z_i is a vector of explanatory variables, γ is a vector of coefficients, and η_i is an error term with standard normal distribution. Z_i includes individual health and socio-demographic characteristics discussed in the previous section.

In the main equation, we focus only on two tobacco product choices, conventional cigarettes and HTPs. Then, the dependent variable, y_i, is now defined by

$y_i = 1$ *iff* individual i is a HTP user

$y_i = 0$ *iff* individual i is a conventional cigarette user

The choice depends on the expected utility of the products, and it is also written as $y_i = 1(X_i\beta + \varepsilon_i > 0)$. X_i is a vector of explanatory variables including individual i's smoking history, health, and sociodemographic characteristics and β is a vector of coefficients. Note that additional variables in smoking history are now included in X_i to explain how nicotine addiction affects individuals' choice on tobacco products.

Finally, assuming that η_i and ε_i are bivariate standard normals with correlation coefficient ρ, the log-likelihood function for the bivariate Probit model with sample selection becomes

$$\begin{aligned}\ln L = &\sum_{i=1}^{N_1} y_i ln\Phi_2(X_i\beta, Z_i\gamma, \rho) \\ &+ \sum_{i=N_1+1}^{N} (1-y_i) ln\Phi_2(-X_i\beta, Z_i\gamma, -\rho) \\ &+ \sum_{i=N+1}^{M} ln\{1-\Phi(Z_i\gamma)\}.\end{aligned}$$

where Φ_2 is the bivariate normal cumulative distribution function and Φ is the cumulative standard normal distribution function.[10] Notice that N_1 observations are HTP users ($y_i = 1$, $s_i = 1$), $N - N_1$ observations are conventional cigarette users ($y_i = 0$, $s_i = 1$), and $M - N$ observations are non-smokers ($s_i = 0$).

[10]Greene (2011) explains appropriate conditional probability for the bivariate Probit model with sample selection.

IV. Empirical results

In Table 3, we present our empirical results that investigate the determinants of switching to HTPs from conventional cigarettes. Column (1) and (2) show the results estimating the sample selection model using both smoker and non-smoker samples. Column (1) reports the first-stage results of the probability that an individual chooses to smoke and Column (2) reports the second-stage results of the probability that a smoker switch from conventional cigarette to HTPs. In Column (3), the estimation result of Probit model for the probability of choosing HTPs using only the smoker sample is presented as a benchmark. This result refers to the estimation without correction for sample selection bias, compared to the result in Column (2).

Column (1) shows the estimation results for the probability that an individual chooses to smoke. First, we find solid results that health concerns play an important role in an individual's decision to start smoking. That is, the higher health interest or health risk individuals have, the less likely they are to choose to smoke. To be specific, it turns out that the respondents who exercise regularly and/or have positive self-confidence in their health are less

Table 3. The determinants of switching to HTPs from conventional cigarettes.

	Sample Selection Model				Probit	
Variables.	1(*Smoking*) (1)		1(*HTPs*) (2)		1(*HTPs*) (3)	
Age of smoking initiation (ref.≥25)						
≤15			−0.090**	(0.039)	−0.182**	(0.078)
16–18			−0.059**	(0.027)	−0.130**	(0.053)
19–24			−0.025	(0.018)	−0.058	(0.040)
ln(cigarettes smoked per week)			−0.003	(0.005)	−0.005	(0.010)
Relative smoking duration(=years from the first smoking/age)			0.088	(0.069)	0.242	(0.147)
Activities for health (ref. no activities)						
Regular Exercise	−0.036*	(0.021)	0.065***	(0.022)	0.083**	(0.033)
Diet therapy	−0.002	(0.025)	0.054**	(0.026)	0.109***	(0.037)
Others(supplements, medical check-up)	0.001	(0.022)	0.019	(0.023)	0.034	(0.032)
Health confidence (ref. very low)						
Low	0.033	(0.028)	0.021	(0.029)	0.057	(0.040)
Medium	0.019	(0.028)	0.064**	(0.029)	0.124***	(0.040)
High	−0.075**	(0.031)	0.120***	(0.032)	0.118**	(0.047)
Very high	−0.101**	(0.049)	0.186***	(0.045)	0.240***	(0.081)
Family health history (ref. no diseases within 4th-degree relatives)						
Any diseases for 4th-degree relatives	−0.068***	(0.022)	0.041*	(0.023)	0.007	(0.036)
One disease for 1st-degree relatives	−0.132***	(0.020)	0.085***	(0.019)	0.002	(0.034)
Two or more diseases for 1st-degree relatives	−0.141***	(0.028)	0.086***	(0.028)	−0.036	(0.050)
Disease	−0.062**	(0.029)	0.050*	(0.030)	0.015	(0.049)
Age (ref.≥50)						
20–29	−0.034	(0.030)	0.082**	(0.041)	0.122*	(0.070)
30–39	−0.010	(0.028)	0.056*	(0.034)	0.076	(0.051)
40–49	0.044	(0.028)	−0.002	(0.031)	0.031	(0.043)
Female (ref. male)	−0.231***	(0.016)	0.172***	(0.015)	0.065***	(0.025)
Occupation (ref. self-employed, farmer)						
Laborer, Technicians/Engineers	−0.010	(0.036)	0.026	(0.035)	0.058	(0.045)
Sales/Service	−0.009	(0.035)	0.027	(0.035)	0.057	(0.046)
Management, Professional	−0.052	(0.037)	0.068*	(0.037)	0.091*	(0.050)
Student	−0.055	(0.042)	0.063	(0.043)	0.057	(0.061)
Office worker	−0.064**	(0.030)	0.079***	(0.030)	0.096**	(0.038)
Unemployed(includes homemaker, retired)	−0.162***	(0.036)	0.137***	(0.035)	0.081	(0.054)
Education (ref. high school diploma or less)						
College degree	−0.020	(0.022)	0.012	(0.023)	−0.000	(0.032)
Bachelor degree	−0.077***	(0.020)	0.067***	(0.021)	0.040	(0.030)
Master degree or higher	−0.138***	(0.032)	0.123***	(0.031)	0.089	(0.055)
living with children aged under 18	−0.039**	(0.019)	0.044**	(0.019)	0.044	(0.028)
living with adult children	−0.069*	(0.036)	0.021	(0.037)	−0.061	(0.060)
Individual income (ref. < 24,000)						
24,000–3,599	0.040*	(0.022)	−0.019	(0.021)	0.012	(0.032)
36,000–59,999	0.095***	(0.024)	−0.052**	(0.023)	0.015	(0.035)
≥60,000	0.083**	(0.034)	−0.013	(0.034)	0.063	(0.049)
Home ownership	0.028*	(0.016)	0.005	(0.016)	0.037	(0.024)
Fisher's z transformed ρ			-14.378***	(0.459)		
Observations	4,514		2,158/4,514		2,158	

This table reports average marginal effects (AMEs) and robust standard errors are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively. All specifications include 17 province dummies in Korea. The unit of individual income is 1,000 KRW (as of 2021, 1,000 KRW = 0.84USD).

likely to choose to smoke. In addition, the coefficients on family health history and disease dummy variables are significantly negative at the 1% significance level, and further their magnitudes increase as closer relatives have medical history related to smoking. These results indicate that those who are vulnerable or sensitive to health risk tend to avoid smoking. Consistent with previous studies (Jones 1994; Lahiri and Song 2000; Yen 2005), we reaffirm the supportive findings that well-being in health provides individuals with strong incentives to quit smoking or to become non-smokers.

Second, the results in Column (1) also show that socio-demographic characteristics have significant effects on the decision of smoking, consistent with our economic intuition. The likelihood of an individual's choosing to smoke decreases when the person is female, highly educated, has an indoor occupation such as office workers, or is unemployed. On the contrary, it turns out that an individual with high income or home ownership is more likely to become a smoker. One might be wondering why a person with a high income or asset is more likely to choose to be a smoker. However, it seems to be natural if we take into account the fact that female full-time homemakers and young single individuals account for a relatively high portion of non-smokers. On the other hand, we find that age is not an important factor in smoking decisions.

Now, let's turn our attention to the estimation results on the determinants of smokers' product choice between conventional cigarettes and HTPs, as presented in Column (2). Herein, we include the variables regarding individual smoking history as additional independent variables in Column (2). By doing so, we are able to explore how nicotine addiction and adolescent smoking affect smokers' product choice.

First, it is noteworthy that most of the estimates in Column (2) have opposite direction to those in Column (1). This indicates that the incentives to quit smoking or become a non-smoker are very similar to the incentive for smokers to switch from conventional cigarettes to HTPs. For instance, we can expect that those who are very sensitive to health risk and tobacco odour are more likely to become non-smokers or choose HTPs if they smoke. Thus, it can be inferred from the result that HTPs may serve as a bridge to smoking cessation.

Second, we find evidence that smoking history has little effect on the decision of smokers to switch to HTPs. The coefficients on amount and duration of smoking are not statistically significant, indicating that nicotine addiction is not an issue for smokers' product choice. The more interesting results are found in ages of smoking initiation. The results show that the coefficients of dummy variables of smoking initiation age under 15 and 16–18 are significantly negative and their magnitudes increase as ages at starting smoking decrease. This indicates that those who start smoking during adolescence are less likely to choose HTPs and rather stick to enjoying conventional cigarettes. Previous studies have exhibited serious concerns about the gateway effect of HTPs or e-cigarettes into smoking, especially in adolescents, because young smokers tend to adopt a novel product more easily and rapidly (Cho et al. 2012; Czoli et al. 2020; McKelvey et al. 2018; Park et al. 2017). However, our results provide supportive evidence that this concern is highly unlikely.

Finally, our empirical results show that health and socio-demographic variables are also important factors that induce smokers to switch to HTPs, providing us with similar implications of the results in Column (1). Those who actively engage in health activities and have high self-confidence in health and family history related to smoking diseases are more likely to choose HTPs as their main tobacco products. In addition, we find that smokers are more likely to switch to HTPs if they were young, were female, were more educated, had under-age children, had indoor occupations such as office workers, management, and professional, or were unemployed.

Most results are consistent with previous studies (Dunbar et al. 2020; Hwang, Ryu, and Park 2019; Kim et al. 2018) and our intuition. However, the effect of income on smoker's product choice is somewhat puzzling. Most coefficients in income are not statistically significant, and we even obtain a significantly negative coefficient in the dummy

variable of income ranged KRW 36–60 million, representative of middle-income class. This indicates that middle-income smokers are less likely to switch to HTPs than low-income smokers. The negative relationship between income and HTP use is contrary to previous findings (Hwang, Ryu, and Park 2019; Kinjo et al. 2020; Wu et al. 2020). We believe that this discrepancy may arise because our estimation did not fully capture age-specific characteristics of HTP adoption. Because HTP is a new product with novel technology applied, it is natural to expect that HTPs are prevalent among young generation with relatively low income as early adopters, whereas HTP adoption would be quite selective among old generation with relatively high income. This implies that the distribution of HTP users are skewed towards low levels of income. As a result, it can be inferred that the positive effects of income on HTP adoption would be diluted. To test this possibility, we repeat the same estimation by age cohort, and the results are presented in Table 4.

Before discussing the empirical result by age cohort, it is necessary to highlight the existence of sample selection bias that would occur when we ignore the decision of non-smokers. Indeed, we find that the Fisher's z transformed ρ, the correlation coefficient between the error terms of the sample selection model, is statistically significant at the 1% significance level, which confirms the existence of sample selection bias in our estimation. In addition, by comparing with the Probit estimates in Column (3) where the sample section bias is not adjusted, we can confirm that selection problem would have confounding effects on our estimation. Although both Probit and sample selection models are similar in terms of direction of the estimates, it appears that they differ in the magnitude and significance of their estimates. To be specific, it turns out that the Probit model tends to overestimate the effects of health interest and smoking history variable on HTPs adoption but undervalues the role of socio-demographic factors such as education and income on smoker's decision to switch to HTPs.[11] All these results imply that the selection problem can lead us to false conclusion and must be treated with caution when evaluating the determinants of product choice of smokers.

Table 4 reports the empirical results by age cohort. As shown, most estimates show similar directions to previous results, though significance may be weakened. Nonetheless, we also find that there are very heterogeneous effects across age cohort, several aspects of which are worth discussing. First, the coefficients on incomes now turn into positive sign with statistical significance for older generation aged over 40 and are not statistically significant for young generation aged 20–39. This indicates that the positive relation between income and HTP adoption becomes evident among relatively older generation. However, income does not seem to be an important factor in the choice for HTP adoption among young generation. This is presumably because the young generation chooses HTPs regardless of their income level. For this reason, we believe that the role of income on HTP adoption was mixed in the previous results in Table 3 because the effects of young generation was dominant.

Second, it is found that the effects of gender on HTP adoption are opposite between young and old generation. Interestingly, among young generation, female smokers are more likely to switch to HTPs, whereas, among old generation, male smokers do. This is expected because young female smokers are more sensitive to tobacco odour and thus choose tobacco products with less odour.

Finally, we find no evidence that smoking in adolescents is associated with HTP adoption, reaffirming our previous results of Table 3. In particular, taking into account that young smokers are major consumers of HTPs, it is noteworthy that adolescent smoking has no effects on HTP adoption of young generations. This evidence supports that it is very unlikely that HTPs serve as a gateway into smoking in adolescents.

V. Conclusion

In this paper, we empirically investigate the determinants that affect smokers to switch to

[11]One plausible explanation lies in the fact that, as shown in Table 1, socio-demographic distributions of conventional cigarette and HTP smokers are very similar, whereas health interests are prominent among HTP smokers than conventional cigarette smokers. As a result, we infer that the effects of socio-demographic characteristics on HTP adoption are underestimated due to little variation between conventional cigarette and HTP smokers by limiting smoker sample only. However, the effects of health interest variables are the opposite.

Table 4. The determinants of switching to HTPs from conventional cigarettes and subsamples.

	Aged 20–39		Aged 40–49		Aged 50–64	
Variables.	1(*HTPs*) (1)		1(*HTPs*) (2)		1(*HTPs*) (3)	
Age of smoking initiation (ref.≥25)						
≤15	−0.015	(0.124)	−0.107	(0.116)	0.122	(0.176)
16–18	0.012	(0.088)	−0.124*	(0.067)	−0.032	(0.079)
19–24	0.066	(0.062)	−0.102**	(0.051)	−0.054	(0.057)
ln(cigarettes smoked per week)	−0.013	(0.011)	0.022*	(0.012)	−0.012	(0.013)
Relative smoking duration(=years from the first smoking/age)	−0.182	(0.256)	0.278	(0.190)	−0.137	(0.253)
Activities for health (ref. no activities)						
Regular Exercise	0.013	(0.038)	0.077*	(0.044)	0.178***	(0.046)
Diet therapy	0.088*	(0.047)	0.098**	(0.048)	0.203***	(0.075)
Others(supplements, medical check-up)	−0.019	(0.039)	0.064	(0.044)	0.025	(0.041)
Health confidence (ref. very low)						
Low	0.074	(0.062)	−0.032	(0.051)	0.046	(0.060)
Medium	0.114*	(0.063)	0.037	(0.052)	0.062	(0.063)
High	0.152**	(0.063)	0.008	(0.066)	−0.060	(0.064)
Very high	0.316***	(0.093)	−0.000	(0.119)	−0.104	(0.087)
Family health history (ref. no diseases within 4th-degree relatives)						
Any diseases for 4th-degree relatives	0.022	(0.044)	0.019	(0.053)	0.005	(0.061)
One disease for 1st-degree relatives	0.079	(0.049)	−0.047	(0.040)	−0.098**	(0.041)
Two or more diseases for 1st-degree relatives	0.010	(0.084)	−0.056	(0.055)	−0.111*	(0.057)
Disease	0.096	(0.068)	−0.097*	(0.050)	0.051	(0.050)
Age	0.006	(0.007)	−0.003	(0.006)	−0.010**	(0.005)
Female (ref. male)	0.168***	(0.036)	−0.116***	(0.031)	−0.136***	(0.037)
Occupation (ref. self-employed, farmer)						
Laborer, Technicians/Engineers	0.038	(0.067)	0.070	(0.049)	0.067	(0.064)
Sales/Service	0.025	(0.066)	0.082	(0.052)	−0.002	(0.070)
Management, Professional	0.119*	(0.069)	0.104*	(0.057)	−0.067	(0.061)
Office worker	0.079	(0.059)	0.150***	(0.039)	0.033	(0.058)
Unemployed(includes students, homemaker, retired)	0.074	(0.069)	0.148**	(0.075)	−0.076	(0.067)
Education (ref. high school diploma or less)						
College degree	0.011	(0.039)	−0.022	(0.045)	−0.031	(0.059)
Bachelor degree	0.064	(0.044)	0.029	(0.045)	−0.010	(0.051)
Master degree or higher	0.137**	(0.067)	0.035	(0.077)	−0.016	(0.065)
living with children aged under 18	0.032	(0.039)	−0.016	(0.030)	−0.091*	(0.052)
living with adult children	0.179	(0.207)	−0.046	(0.138)	−0.066*	(0.036)
Individual income (ref. < 24,000)						
24,000–3,599	−0.025	(0.035)	0.127***	(0.044)	0.095*	(0.053)
36,000–59,999	−0.055	(0.041)	0.146***	(0.041)	0.045	(0.049)
≥60,000	−0.073	(0.071)	0.142**	(0.057)	0.109*	(0.063)
Home ownership	0.053	(0.036)	−0.015	(0.032)	−0.034	(0.044)
Fisher's z transformed ρ	−0.634	(0.478)	15.554***	(0.122)	-15.2***	(0.417)
Observations	1,337/2,916		562/1,037		259/561	

This table reports average marginal effects (AMEs) and robust standard errors are in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively. All specifications include 16 province dummies and Age is a continuous variable in terms of years. Occupation and province dummies are slightly adjusted from the main results so each subsample has variation within the dummy. Students are included in the unemployed category and two small provinces (Jeju island and Sejong city) are integrated into one region. The unit of individual income is 1,000 KRW (as of 2021, 1,000 KRW = 0.84USD).

HTPs from conventional cigarettes. To do so, we collected survey data in 2020 for Korean adults, including 2,158 smokers and 2,356 non-smokers. To alleviate the selection bias, we employ the bivariate Probit model with sample selection. In the sequential procedure, we estimate the probability that individuals choose to smoke at the selection stage, and estimate the probability that smokers switch to HTPs at the second stage.

Our findings can be summarized as follows: First, we found that health and socio-demographic variables are major determinants in both smoking initiation and tobacco product choices rather than smoking history. The smokers were more likely to switch to HTPs if they were young, were female, were more educated, had under-age children, had indoor occupations, had higher health interest, and had higher health risk. Second, the incentives to switch to HTPs from conventional cigarettes are aligned with the incentives to quit smoking or become a non-smoker. This implies that we can consider HTP adoption as a possible policy tool for smoking cessation. Third, our results show that there is no positive association between smoking in adolescents and HTP adoption, disproving the gateway effect of HTPs concerned by Czoli et al. (2020) and McKelvey et al. (2018). Finally, we find that the heterogeneity of HTP adoption across

age cohort is present as HTP appeals strongly to young smokers as a new technology. To be specific, young generations were more likely to switch to HTPs if they are female, and choose HTPs regardless of individual income. In contrast, old generations aged over 40 were more likely to switch to HTPs if they were male and earned more income.

This paper provides several implications of particular interest to health policymakers. We suggest that HTP can be considered as a policy tool for designing tobacco control policy for smoking cessation by showing that the incentives for smoking cessation and HTP adoption are aligned, together with evidence of no gateway effects of HTPs. In addition, our results regarding the heterogeneous incentives for HTP adoption by age cohort imply that age-targeting policy on HTPs is necessary.

Besides, we believe that our empirical results can provide further policy implications regarding tobacco regulatory system including taxation and market regulation. For example, excise tax on cigarettes in Korea has been revised to equalize the final consumer prices of all kinds of cigarettes. The tax rate adjustment aimed to prevent smokers from consumption replacement (especially, conventional cigarettes with HTPs). If HTPs are no better than conventional cigarettes, then this price equalizing policy can be justified. However, if the former has more positive functions than the latter (that is to say, the former has smaller negative externalities), it will be reasonable to impose tax rates according to the size of external costs. Recent research including this study shows the possibility that HTPs are less harmful or more helpful to quit smoking than conventional cigarettes (Dusautoir et al. 2021; Esposito et al. 2022; Polosa et al. 2021). These results imply that both taxation and market regulation need to be designed to induce smokers to substitute HTPs for conventional ones.

This study has several limitations. First, one clear limitation is that our study did not directly investigate the dynamic switching behaviour from conventional cigarettes to HTPs because the data do not provide the exact information about this switching behaviour. Instead, using a static model, we drew inferences regarding the switching behaviour based on the assumption that all current HTP smokers have switched from conventional cigarettes. We justified this using public statistics, confirming that almost all HTP smokers have indeed switched from conventional cigarettes. However, investigating the dynamic switching behaviours among tobacco products is still an important research topic. It should be examined by future studies using better panel dataset. Second, our study intentionally ignored the existence of dual (or multiple) users of tobacco products and forced smokers to be classified into two separate categories. This was because our research purpose was to examine the determinants that lead smokers to switch from conventional cigarettes to HTPs. However, there is a vast literature (e.g. Chen et al. 2021; Delnevo et al. 2016; Harlow et al. 2022; Little et al. 2016; Simonavicius et al. 2020) that examined various consumption patterns related to tobacco products and derived meaningful policy implications for tobacco control. As HTP is a popular new tobacco product worldwide, this topic merits a revisit.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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