



Article

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A Health Economics Inquiry into Regulatory Constraints on the European Tobacco Market

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Abstract: Despite the implementation of significant measures by European countries in recent years, smoking rates in Europe remain persistently high. The European Commission is currently undertaking a comprehensive review of its tobacco regulations. This article aims to address critical inquiries that arise during the amendment of the regulatory framework. We evaluate the effectiveness of existing tobacco control methods and observe a diminishing impact on promoting smoking cessation. Additionally, we explore how individuals of varying genders respond to the regulatory environment. We propose a comprehensive and evidence-based framework for implementing a taxation system in response to the proliferation of emerging products, including e-cigarettes and heated tobacco. This system is designed to align effectively with health policy objectives, providing a strategic approach to curbing tobacco use and promoting public health.

Keywords: smoking prevalence; tobacco control policy; taxation; gender-specific responses

Jel Classifications: I 18

1 Introduction

European nations have made persistent efforts to reduce smoking rates over the past two decades. Notwithstanding these efforts, smoking prevalences in Europe are relatively high in the global comparison (Janssen, El Gewily, and Bardoutsos 2020), ranging from 17 % to approximately 40 %, with an average prevalence of 27.5 % in

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2018. In contrast, the estimated smoking rate for the United States in the same year stood at 20 % according to WHO estimations (Zarca and Filipovic-Pierucci 2024). Over the period between 2005 and 2018, the prevalence of smoking in Europe witnessed a reduction of 17.4 %, while the decrease in the United States was more substantial at 22.5 %.

These statistics underscore the formidable challenge European nations face in achieving the ambitious goal set by the European Union to reduce the proportion of tobacco smokers to less than 5 % by 2040. This objective appears akin to a Sisyphean task, considering the historical trends and the existing prevalence rates. The complexities involved in altering deeply ingrained smoking behaviors necessitate a critical examination of the strategies employed thus far and a recalibration of approaches to meet the established targets.

The imperative to decrease smoking is paramount, given the devastating repercussions of smoking on society. Non-communicable diseases persist as a leading cause of preventable premature deaths in Europe. The European Commission reports that approximately 80 % of the disease burden in EU-27 nations is attributed to these disorders, resulting in significant societal expenditures. Recognizing the profound impact on public health and economics, there is a compelling argument for the consideration of a complete smoking prohibition. However, acknowledging the practical challenges associated with such a drastic measure, it appears improbable that the European Commission would advocate for a total ban.

Instead, the E.U. Commission adopts a more pragmatic approach, offering incentives to encourage individuals to quit or reduce tobacco smoking. For instance, the Council Directive 2011/64/E.U. outlines the structure and excise duty rates applied to manufactured tobacco products in E.U. member states. The directive explicitly aims to "ensure the proper functioning of the internal market and, at the same time, a high level of health protection" (par. (2)). By employing fiscal measures and taxation policies, the E.U. Commission endeavors to strike a balance between economic considerations and public health objectives in the regulation of tobacco products.

The effectiveness of the existing Directive is subject to skepticism, and the European Commission itself acknowledges uncertainties, prompting a current evaluation of the Directive. This assessment is crucial, particularly considering the evolving landscape of tobacco products and the surge in market share for non-combustible alternatives (NCAs) like e-cigarettes and heated tobacco products (HTP). Notably, the current Directive lacks specific provisions addressing these emerging alternatives. The market dynamics indicate a substantial increase in the popularity of NCAs, with the anticipation of their growing significance. Recognizing their potential as a reduced-risk option for smokers compared to traditional cigarettes, it becomes imperative to scrutinize the taxation of NCAs. This evaluation is integral to achieving the objectives outlined by the E.U. Commission, as it necessitates aligning taxation policies with the evolving tobacco

market to ensure effective regulation and the promotion of public health. As part of this assessment, it is essential to explore how the taxation of NCAs can contribute to the overarching goals set by the E.U. Commission in reducing tobacco-related harm and fostering a healthier society.

In addition, it is crucial to consider other influencing factors. Evidence from the United States, as highlighted by (Hansen, Sabia, and Rees 2017), suggests a diminishing efficacy of traditional tobacco control strategies. We will demonstrate that similar evidence of this trend is relevant to the European context (Chapter 2.2). Moreover, there exists a notable gender disparity in the decline of smoking rates across Europe. While the decrease in male smoking rates is substantial, the corresponding reduction in female smoking rates is less pronounced. This gender-specific trend is visually represented in Figure 1. A more comprehensive exploration of these gender-specific disparities is undertaken in Chapter 2.3, delving into the underlying factors contributing to this observed divergence in smoking behaviors. Understanding and addressing these gender-specific patterns is essential for formulating targeted and effective tobacco control measures in the European context.

When evaluating an appropriate tax environment for NCAs, it is crucial to assess how variations in duty prices mutually influence the demand for each product. If smokers do not abandon smoking due to price increases, the optimal strategy would be for them to transition to less harmful alternatives. To facilitate this shift, it is necessary for both traditional cigarettes and NCAs to be considered substitutes

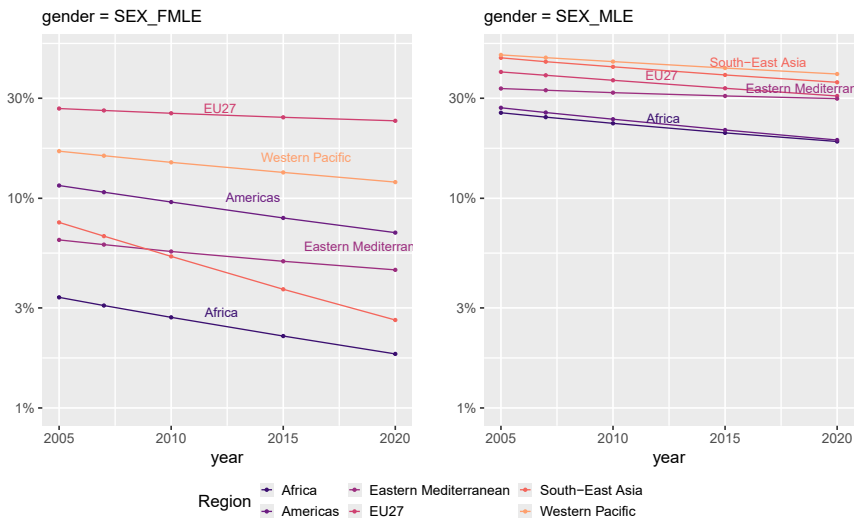


Figure 1: Tobacco-smoking prevalence estimates (age-standardized rates) by gender in the EU-27 and other regions. Data source: WHO (Global Health Observatory).

rather than complements. Understanding the dynamics of this interaction is vital for designing effective policy interventions that encourage the desired behavioral change among consumers. This nuanced comprehension is essential for formulating tax policies that not only align with health objectives but also consider the economic incentives influencing consumer choices in the tobacco market.

When imposing taxes on products, assessing the degree of health risk they pose is imperative. Empirical data indicates that NCAs have a lower level of harm compared to traditional combustible cigarettes, which still dominate the market. The prevailing consensus suggests that substituting flammable substances with NCAs is associated with a harm reduction. In Chapter 3, we survey the existing knowledge regarding NCAs and their harmfulness compared to combustible substances, drawing on evidence from the United States. In research on European markets, there seems to be limited awareness of this substitute/complement relationship. To shed light on this matter, we utilize data from the Eurobarometer (European Commission 2021a, 2021b). Our primary focus is on discerning the inclination of European NCA users to transition away from combustible products. To the best of our knowledge, this article marks the inaugural effort to evaluate the substitutive nature of various products in the European tobacco market.

The prevalence of smoking and tobacco use is routinely assessed as the percentage of the population that consumes cigarettes and other tobacco products (refer to WHO statistics). The increasing market presence of NCAs raises the question of whether such prevalence measures are reliable for assessing public health protection. Although NCAs are comparatively less harmful than traditional combustible products, it is crucial to acknowledge that their use is not risk-free. Thus, relying solely on smoking prevalence may not provide a holistic understanding of the situation, as it neglects the potential harmful effects of NCA consumption on public health. To address this limitation, Chapter 6 introduces an alternative measure: the overall risk level associated with various tobacco substances. This metric offers a more comprehensive evaluation of the health impact, encompassing combustible and non-combustible products. By considering the overall risk associated with different tobacco products, this measure provides a nuanced perspective on the public health implications of tobacco consumption beyond the scope of traditional smoking prevalence metrics.

This paper aims to provide insights into two key questions:

1. How is the European market expected to react to the taxation of Non-Combustible Alternatives (NCAs)?
2. What is the European consumers' perception of combustible products and their non-combustible alternatives?

To address these questions, the paper is structured as follows: First, we present an overview of the current regulatory framework regarding the taxation of tobacco

products at the EU-27 level and investigate whether the existing Directive contributes successfully to the objectives set by the E.U. Commission (Chapter 2). Secondly, we delve into the substitutive interplay between products in the European tobacco market, providing a survey of existing studies in Chapters 3 and 4. In particular, we examine empirical evidence on U.S. consumers' responses to e-cigarette taxation and its impact on smoking prevalence. Thirdly, using data from the Eurobarometer, we assess the reasons for substituting combustibles with less harmful products in Chapter 5. Our findings reveal that NCAs act as substitutes for conventional cigarettes. Finally, we derive policy implications within a theoretical framework (Chapter 6) and argue that the current focus on smoking cessation should transition to a more comprehensive health measure considering the lower but still existing health risk associated with NCAs.

2 European Tobacco Control Policy

2.1 European Tobacco Tax Environment

Directive 2011/64/E.U. determines the structure and excise duty rates applied to manufactured tobacco products in the E.U. member states. It then levies minimum excise duties on tobacco products to reach these goals. The E.U. Commission concludes that the Directive's objective of reducing price differentials between E.U. member states has not been achieved. Thus, the notable differences in excise tax yields in 2019 seem to translate into price differences. European Commission et al. (2020) even states that the gap between countries with the lowest and highest taxes slightly increased.

Several E.U. member states have implemented taxes on e-cigarettes and heated tobacco products. These taxes vary in structure and rates,¹ posing a challenge to the Directive's goal of harmonizing prices. In response to the evolving market landscape and a critical evaluation of its efficacy, the E.U. Directive is currently under review. The pivotal question is how to address the taxation of NCAs.

2.2 Effectiveness of Tobacco Control Policies

The attainment of the European Union's objective to reduce smoking prevalence is questionable. Figure 1 illustrates WHO estimates of tobacco-smoking prevalence by gender (FMLE: female, MLE: male). Despite a decreasing trend, smoking prevalence

¹ For instance, some countries tax HTP by weight, while others tax by the stick. Tax rates range from zero (temporarily in Poland and the Czech Republic) to €200 per kg in Italy (European Commission et al. (2020)).

remains relatively high across EU-27 member states. The goal to reduce the share of tobacco users to below 5 % by 2040, as outlined in *Europe's Beating Cancer Plan*, appears ambitious given the current prevalence of around 25 %.

Multiple studies advocate for enhancing tobacco control regulations in the European Union to achieve the ambitious objectives. The Tobacco Control Scale (TCS) (Joossens and Raw 2006) monitors European countries' tobacco control measures. The TCS incorporates weighted metrics aligned with WHO guidelines, considering factors such as tax-induced cigarette prices, restrictions on smoking in public places, and health warning regulations on products. A total of nine policy fields are assessed. In a comparative analysis of TCS scores, smoking prevalences, and quitting rates from 2006 to 2014, Feliu et al. (2019) found that European nations with more strong tobacco control efforts exhibit lower prevalence rates. Consequently, the authors advocate for intensifying comprehensive tobacco control measures as a policy proposal.

Similar advice is echoed in the United States; however, the evidence presented by Hansen, Sabia, and Rees (2017) suggests a diminishing belief in the efficacy of established tobacco control policies over time. Hansen et al. provides an updated version of a widely referenced work by Carpenter and Cook (2008), demonstrating a significant inverse correlation between cigarette taxes and smoking prevalence among young individuals. Hansen et al. utilizes the same dataset, the *Youth Risk Behavior Surveys*, extending the initial observation time-frame from 1991 to 2005 by incorporating four additional recent waves. The once robust effect observed in the earlier study has considerably weakened.

Building on the methodology employed by Feliu et al. (2019) for the European case, we utilize the same methods and data source (Eurobarometer). Our modification involves extending the observation period by an additional six years, covering the years 2006–2020. The left panel in Figure 2 replicates the original study, indicating a statistically significant negative correlation. However, for the extended observation period, we use the TCS score from 2019, reflecting countries' efforts during the expanded time frame. The impact diminishes significantly, and the relationship becomes statistically insignificant. These results are depicted in the right panel of Figure 2.

2.3 Gender-Specific Developments in Smoking Prevalence

An intriguing observation emerges from the differing trends in smoking prevalence among females and males. While the prevalence among men has significantly decreased and aligns with trends in other regions, smoking prevalence among women remains notably high in the EU-27 member states. Limited progress is evident in reducing this rate among women (see Figure 1). This gender-specific variation

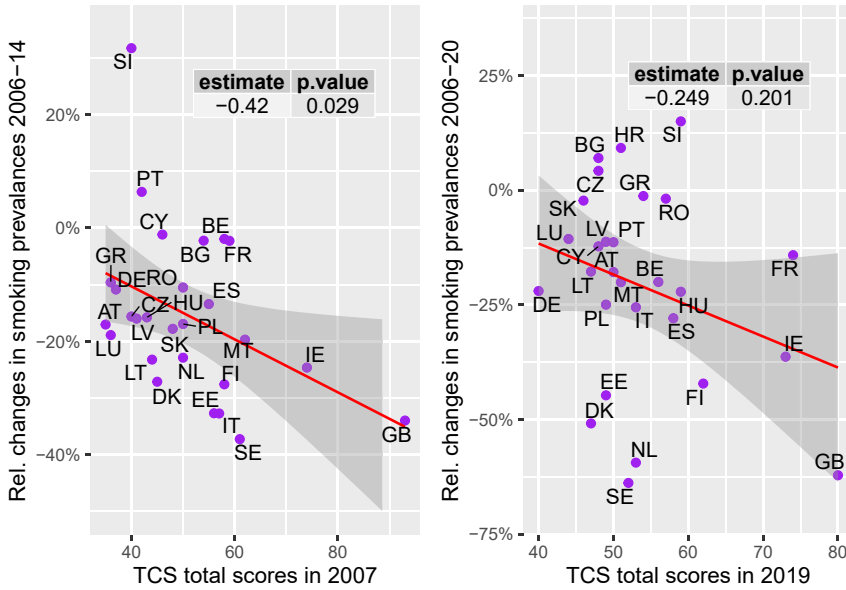


Figure 2: Relative changes in smoking rates versus TCS scores in the EU-27 + Great Britain. Data: Eurobarometer.

highlights the need for targeted interventions to address the persistently high smoking prevalence among females in the European context.

A plausible explanation could be a 'low-level effect': the prevalence of smoking among females is already so low that there is limited potential for further decline. Examining country-specific statistics introduces uncertainty regarding whether the relatively low rates of smoking among women significantly contribute to the stagnation in their smoking rates. The rates among females did not decrease until they became stable. Instead, we explore countries that initially had meager smoking rates in 2000 and then experienced a significant surge in the subsequent years. Conversely, countries with initially elevated smoking rates witnessed a substantial decrease, falling below the minimum level observed in 2000. Overall, the analysis of female prevalence in different countries reveals distinct and divergent trends, suggesting that the somewhat lower average level compared to men is unlikely to be the driving factor. The data are depicted in Appendix B.

The differences in smoking prevalence between genders suggest varying responses to the common regulatory environment, prompting a reevaluation of the impact of chosen policy measures. While these measures appear effective for the male population, they seem to have limited impact on the female population. The European Commission (European Commission et al. 2020) and recent literature

address these gender differences in response to tobacco-policy measures. For instance, Ngo et al. (2019) argue that, although female smokers are more responsive to an average tax increase, they appear less responsive to Value-Added Tax (VAT) increases. Empirical studies focused on the U.S. context reveal a contrasting trend compared to the European case. The majority of these studies suggest that men exhibit greater responsiveness to cigarette taxes than women, although it is essential to note that this finding is subject to debate (refer to Stehr (2007) for a comprehensive overview).²

Why do we emphasize gender-specific differences? As we will elaborate below, the European Commission has set ambitious goals that it seeks to achieve with a package of measures. We have not yet found any indication that the EU Commission has ever investigated the gender-specific effectiveness of its measures. So far, it seems to be assumed that the measures have an equal impact. However, our analyses show that this cannot necessarily be assumed.

Examining the applied excise tax yield and the trends in smoking prevalence in the EU-27 member states for both men and women suggests that the Directive's impact on achieving its objectives is limited. Furthermore, the evolving market landscape underscores the necessity to reassess the current Directive. It focuses on cigarettes, fine-cut tobacco, cigars, cigarillos, and other smoking tobacco, with NCAs not explicitly covered. In the upcoming chapter, we will delve into the existing knowledge regarding the relative harmfulness of NCAs.

3 Harmfulness of Combustibles versus NCAs

While the market for e-cigarettes and Heated Tobacco Products (HTP) is currently smaller compared to conventional tobacco products like cigarettes, their substantial market growth signals a continuing and significant role in the tobacco market.³ When regulating and taxing these emerging products, the emphasis should be on understanding the distinct health threats they pose. Evidence suggests that NCAs are less

² The literature consistently finds gender differences in response to cigarette taxes and price increases. For example, Chaloupka and Pacula (1999) find that the price elasticity for cigarettes among young men is almost twice as high as among women. Gallet and List (2003) find the demand of men to be more elastic than that of women (average price elasticity among men is -0.50 , and among women, it is -0.34). Palali and van Ours (2019) report that a price increase inversely affects males' starting rate of smoking.

³ For instance, European Commission et al. (2020) notes that the number of regular e-cigarette users increased from 6 to more than 12 million between 2013 and 2017, and HTP users increased to 1.3 million between 2016 and 2018. Since 2014, e-cigarettes have been the most commonly used tobacco product among adolescents in the U.S (Cullen et al. 2019; Gentzke et al. 2019).

harmful than combustible cigarettes. The 2018 report of the National Academies of Sciences, Engineering, and Medicine (2018, p. 1) summarizes that "Laboratory tests of e-cigarette ingredients [...] suggest that e-cigarettes are likely to be far less harmful than combustible tobacco cigarettes." Thus, the National Academies concluded that "if e-cigarette use by adult smokers leads to long-term abstinence from combustible tobacco cigarettes, the benefit to public health could be considerable."

In a report commissioned by Public Health England, McNeill et al. (2018, p. 20) provided the following policy advice: "Vaping poses only a small fraction of the risks of smoking, and switching completely from smoking to vaping conveys substantial health benefits over continued smoking. Based on current knowledge, stating that vaping is at least 95 % less harmful than smoking remains a good way to communicate the large difference in relative risk unambiguously so that more smokers are encouraged to make the switch from smoking to vaping." Although the 95 % figure reported by McNeill et al. has been questioned,⁴ it is generally accepted that substituting combustible products with NCAs is associated with harm reduction. According to Allcott and Raffkin (2022), who interviewed 137 experts from various disciplines, the majority believe that the harm levels are closer than alleged. Experts state that NCAs are, on average, 63 % less harmful than combustibles, not 95 %. The substitution relationship between NCAs and cigarettes is of concern to policymakers, as restricting e-cigarettes may potentially increase the demand for much more harmful products like cigarettes.

The different harm levels of combustible tobacco products and NCAs are only *one* factor to consider when finding an appropriate tax environment. Another critical factor is understanding how different duty prices influence the demand for each product. If escalating prices do not lead some smokers to quit, the subsequent best response would be to switch to less harmful products. This transition is contingent on both products being substitutes rather than complements. Therefore, comprehending the dynamic interplay between these products is vital for effective policy measures.

4 Recent Empirical Evidence from the U.S.

We will briefly review the most recent studies, which predominantly focus on U.S. *data*, underscoring the necessity for additional research in the European context.⁵ For a more extended survey for the U.S., see Prieger (2023).

⁴ Glantz and Bareham (2018, p. 223) questioned the evidence on safety and efficacy of the 95 % result.

⁵ For differences in cigarette smoking prevalence, tobacco smoking prevalence, and tobacco use prevalence between the U.S. market and selected European markets, see Table 3 in the Appendix.

Minnesota became the first U.S. state to tax e-cigarettes in 2010.⁶ Initially, a tax of 35 % on the wholesale price was imposed, and three years later, the rate was increased to 95 %. Saffer et al. (2020) found that the e-cigarette tax in Minnesota led to an increase in adult smoking and a reduction in smoking cessation. The estimated cross-price elasticity (the elasticity of smoking prevalence concerning e-cigarette prices) is 0.13. This implies that a 10 % increase in e-cigarette prices is estimated to have increased smoking prevalence by 1.3 %. Extrapolating Minnesota data to the national U.S. level, they estimate that taxing e-cigarettes at the same rate as combustible cigarettes would deter approximately a quarter of potential quitters (around 2.75 million U.S. citizens) from cessation.

The estimate of around 2.75 million (henceforth: *m*) potential quitters who could be deterred from quitting smoking aligns with a similar estimate by Pesko, Courtemanche, and Maclean (2020). They project an additional 2.5 million adult smokers if a nationwide e-cigarette tax of 1.65 per milliliter (ml) of vaping liquid were implemented. Using survey data from 2011 to 2018, they observed that e-cigarette taxes are associated with an increased use of combustible cigarettes, indicating a positive cross-price elasticity. Specifically, they found that a \$1.00 increase in tax (per ml of vaping liquid) raises daily smoking propensity by 5.3 %.

Utilizing data from approximately 94,000 students and their smoking and vaping behavior between 2011 and 2015, Pesko and Warman (2022) present strong evidence for a substitutive relationship between e-cigarettes and combustibles. Their primary focus is on the number of cigarettes smoked following an increase in e-cigarette prices. They estimate that a \$1.00 e-cigarette price increase results in a monthly increase in cigarette demand, ranging between 3.6 and 4.8 daily average cigarette sticks consumed per smoker. Consistent with Pesko, Courtemanche, and Maclean (2020), they also identify higher responsiveness to prices among younger adults.

In conclusion, two recent studies with significant methodological overlap provide noteworthy insights. Allcott and Rafkin (2022) argue that the positive cross-price elasticity of cigarette demand concerning e-cigarette prices becomes insignificant when accounting for pre-existing sale trends. Their simulation results on optimal e-cigarette taxes depend on various parameters, including the relative harm level of e-cigarettes compared to combustibles and the actual cross-price elasticities, which hinge on the specification of the general sale trend. Although Allcott and Rafkin (2022) employ a more sophisticated model than in the previous chapter, the crucial parameters for assessing the optimal tax remain consistent. The optimal e-cigarette tax varies from prohibitively high to negative (indicating a subsidy for e-cigarettes), contingent on the elasticity and harm level specifications. Additionally, there is the possibility that

⁶ As of mid-2021, 28 U.S. states and Washington DC had implemented taxes on e-cigarettes. The varying rates and bases can be explored on the Tax Foundation website. See also Abouk et al. (2023b).

smoking and vaping act as substitutes for older individuals but as complements for younger consumers, suggesting a negative cross-price effect for youths.

The primary distinction in the paper by Cotti et al. (2022) compared to Allcott and Rafkin (2022) lies in considering an extended time period. While both studies utilize the same data source, Allcott and Rafkin (2022) focuses on the period from 2013 to 2017, Cotti et al. (2022) extends the analysis by incorporating two subsequent years until 2019. Although these two years may seem brief, they are crucial as the e-cigarette market experienced significant expansion after 2017. Furthermore, there were substantial changes in the regulatory environment; by the end of 2019, seventeen states had implemented taxes on e-cigarettes, compared to only seven states two years earlier, which only taxed vaping devices. The differences in results across studies are noticeable. In Cotti et al. (2022), the cross-price estimate is 0.5, while Abouk et al. (2023b) find a cross-price elasticity from e-cigarettes to combustibles of 0.34 for U.S. adults between 2010 and 2019.⁷ The only somewhat recent study for European countries by Stoklosa, Drope, and Chaloupka (2016) also supports a similar conclusion. They estimate an own-price elasticity of e-cigarettes at -0.8 . Unfortunately, they couldn't precisely calculate the effect of e-cigarette prices on cigarette demand.⁸

Table 1 provides a rough summary of recent studies on cross-price elasticity estimates. More recent studies have found significantly higher cross-impacts than the earlier examination by Zheng et al. (2016), who reported a cross-price elasticity of 0.004 for cigarette demand. The increase in cross-price effects over time is not surprising. E-cigarettes have become a significant part of tobacco markets in recent years, leading to an increase in their price level and a decrease in the quantities of cigarettes.⁹

The overwhelming evidence strongly indicates that e-cigarettes and combustible cigarettes function as substitutes. Consequently, there is a valid concern about the potential unintended consequence of an increase in cigarette smoking resulting from a tax hike on e-cigarettes. However, it is crucial to emphasize that all prior studies rely on data from the U.S., and recent studies specific to Europe are not yet available. The subsequent chapter represents the initial effort to address this gap in the literature.

⁷ More studies are surveyed by (Pesko and Warman 2022, p. 137).

⁸ Their conclusion that cigarettes and e-cigarettes are economic substitutes is based on the inverse cross-price elasticity, i.e., from cigarette price to e-cigarette demand (of about 4.6). The authors emphasize that this exceptionally high number is due to the tiny size of the e-cigarette market in the considered years (2011–2014).

⁹ Since the cross-price elasticity is $\eta_{e,c} = x'_c(p_e) \cdot \frac{p_e}{x_c}$, both mentioned effects increase the second factor.

Table 1: Survey Table on recent studies – Effect of e-cigarette prices on combustible-cigarette demand.

Source	Obs. period	Focus group	Effect
Pesko and Warman (2022)	2011–2015	Youths	\$1.00 \uparrow \Rightarrow [3.8, 4.6] c./m. 100 % ad val. \uparrow \Rightarrow 7.9 % \uparrow
Allcott and Rafkin (2022)	2011–2017	Overall	Ambiguous
Abouk et al. (2023b)	2010–2019	Youths	$\eta_{e,c} = +0.34$
Pesko, Courtemanche, and Maclean (2020)	2011–2018	Adults	\$1.00 \uparrow \Rightarrow 5.3 % \uparrow .
Cotti et al. (2022)	2011–2019	Overall	\$1.00 \uparrow \Rightarrow 10 % \uparrow $\eta_{e,c} = +0.50$
Saffer et al. (2020)	2010–2015	Adults	$\eta_{e,c} = +0.13$
Abouk et al. (2023a)	2013–2017	Pregnants	\$1.00 \uparrow \Rightarrow 0.04pp \uparrow

5 Consumers' Perception of Combustibles and NCA in the European Union

This chapter presents several empirical findings on this interplay using the widely utilized Eurobarometer surveys for the years 2017 and 2020 (see European Commission (2021a, 2021b)).¹⁰ Additionally, a difference-in-differences case study assesses the causal relationship between e-cigarette prices and combustible cigarette consumption. This case study contributes additional evidence to whether e-cigarettes and combustible cigarettes act as substitutes or complements.

Figure 3 shows the relationship between e-cigarette use (vaping) and cigarette smokers' behavior. The plot on the left-hand side depicts the correlation between cigarette smoking prevalence and vaping. The plot on the right shows the correlation between those who quit smoking and those who vape e-cigarettes. The different label colors indicate EU-27 member states' regional affiliations.

Through the analysis of the data, two main insights were revealed:

1. The relationship between cigarette smoking prevalence and e-cigarette vaping is ambiguous. The estimated Pearson correlation coefficient of $\tau = 0.022$ is not significantly positive (p -value = 0.912). This unclear relationship also holds when considering only women ($\tau = -0.19$, $p = 0.34$) or only men ($\tau = 0.012$, $p = 0.95$) in the analysis.
2. When assessing the number of individuals who quit cigarette smoking to the number of e-cigarette vapers, a positive correlation is observed. Countries with

¹⁰ For instance, Eurobarometer data were employed by Bogdanovica et al. (2010); Laverty, Vardavas, and Filippidis (2021), and others. See Laverty, Vardavas, and Filippidis (2021) for a description of the Eurobarometer data.

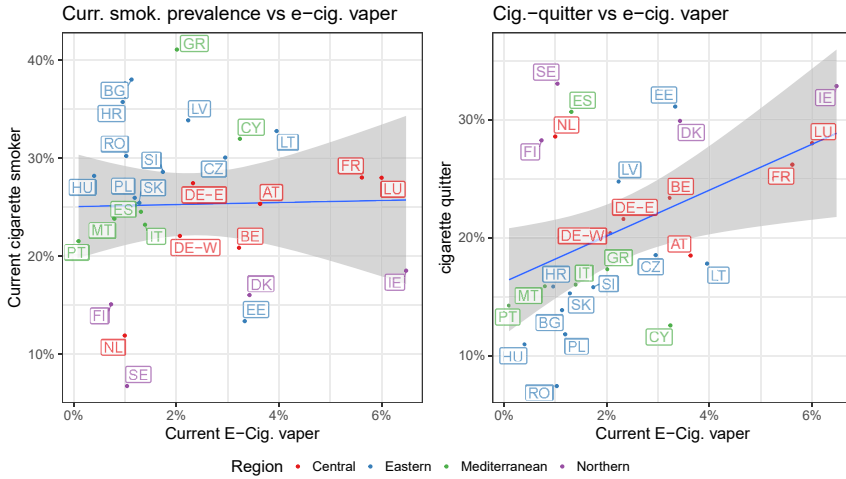


Figure 3: Combustible use and vaping behavior in European countries, 2020.

more quitters tend to have a higher share of e-cigarette vapers ($\tau = 0.44, p = 0.017$). This apparent relationship between quitters, on the one hand, and e-cigarette vapers, on the other hand, however, varies significantly between genders. Among women, the positive relationship is strong and highly significant ($\tau = 0.5, p = 0.006$), whereas among men, the estimated correlation coefficient is weaker and not significant ($\tau = 0.35, p = 0.06$).

These findings suggest that EU citizens use e-cigarettes as a substitute for cigarettes, aligning with a widely established conclusion for the U.S. (see Chapter 4). This proposition is further supported by data reflecting survey participants’ responses regarding the factors influencing their decision to start using e-cigarettes or heated tobacco products (HTP). The available reasons for selection and the survey participants’ answers are depicted in Figure 4.

1. To stop or reduce tobacco consumption (short: "Reduce.tob"),
2. They were cool or attractive ("Cool.attractive"),
3. Because e-cigarettes can be vaped in places where tobacco smoking was not allowed ("Places"),
4. Because they were cheaper than tobacco ("Price"),
5. Because of friends using e-cigarettes ("Friends"),
6. Due to the flavors of e-cigarettes ("Flavour"),
7. Because one regarded e-cigarettes as less harmful than using tobacco ("Less.Harmful"), and
8. Other reasons ("Others").

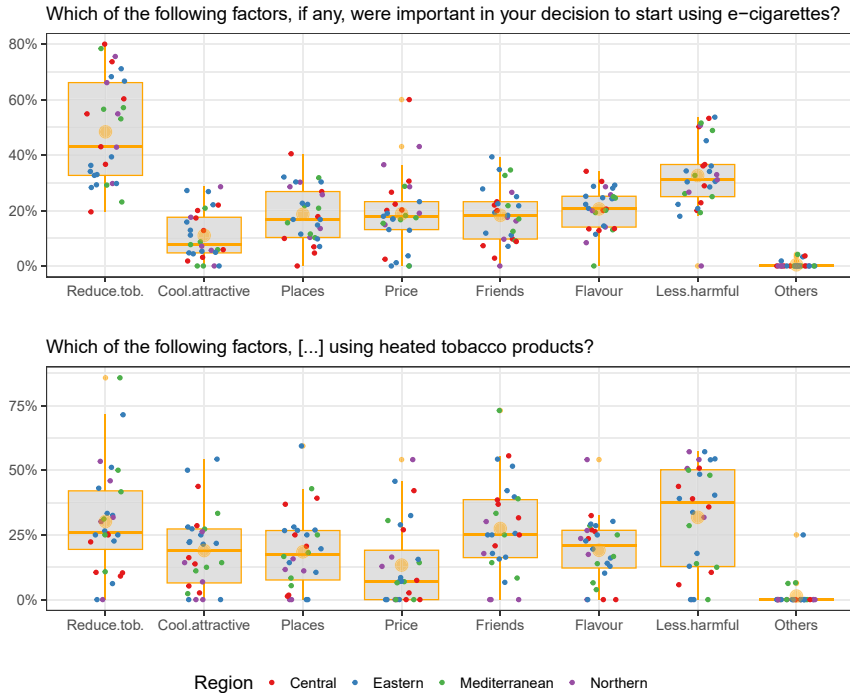


Figure 4: Factors for entry into e-cigarettes and heated-tobacco use. *Note:* The interquartile range (25th to 75th percentiles) is located within the boxes, such that the median value splits the boxes. Each country's actual (average) value is represented by the points lying on the boxplots. The reasons differ from country to country, and the different colors indicate countries' regional affiliations.

The boxplots in Figure 4 display the distribution for each factor influencing the first use of e-cigarettes (upper plots) and heated tobacco products (HTPs, lower plot). According to the data, the predominant reason for starting to use e-cigarettes is to stop or reduce tobacco consumption, with approximately 48% indicating this as a primary motive. All other reasons play a comparatively smaller role. These results align with those reported by Berg et al. (2014) using U.S. *data*. Interestingly, the landscape has undergone a fundamental shift in recent years. In 2014, the most critical factors were "Flavor" (39%) and "Price" (38%) (see Stoklosa, Drope, and Chaloupka 2016, p. 1974).

Here, too, we find remarkable differences between genders. Women significantly more often than men report that the reduction of tobacco consumption is a reason for using e-cigarettes (Women: 0.591 [0.578, 0.602], Men: 0.562 [0.552, 0.572]), with confidence intervals calculated using the Wilson score interval for binomial probabilities (Wilson 1927).

We observe the same pattern regarding the variable "Less.Harmful". Significantly more women than men cite the (supposedly) lower health risk as a reason for switching from combustibles to e-cigarettes (Females: 0.38 [0.374, 0.396], Males: 0.352 [0.342, 0.362]). Men, on the other hand, emphasize reasons more related to regulatory measures (such as "Places") and "Flavor". Overall, it appears that women are more likely to switch for motives that align with public health objectives.

Analyzing reasons for HTP use reveals that, on average, the belief that heated tobacco is less harmful than combustibles is the primary reason for starting to use HTP. Recent assessments by Laverty, Vardavas, and Filippidis (2021) using Eurobarometer data also support this trend. Reducing or stopping cigarette smoking also plays a prominent role in the initial use of HTP. Therefore, one can conclude that e-cigarettes and HTPs are used as combustible substitutes.

Furthermore, we present a case study from Poland to further investigate the relationship between combustibles and e-cigarettes. Poland introduced an excise tax on e-cigarettes in 2020 (WBG Global Tobacco Control Program Team 2019). In a difference-in-differences estimation using Spain as a control group, where the tax environment on e-cigarettes remained unaltered, the study observes whether combustible consumption in Poland significantly changed in response to the introduction of the e-cigarette tax.

Two primary factors drive the selection of Poland and Spain for our approach. First, the tobacco markets in these countries are of similar size and composition, making them comparable. Second, the analysis necessitates identifying a pair of countries where one introduced an e-cigarette tax within the considered time frame while the other did not. Additionally, it is crucial that other regulations affecting cigarette consumption, specifically taxes on combustibles, remain relatively stable. This criterion excludes most EU countries from the analysis, as many have experienced significant increases in cigarette taxes, ranging from 20 % to 50 % in recent years. Among the remaining countries with excise tax yield increases of less than 10 %, several are unsuitable due to the unique characteristics of their tobacco markets. For example, Luxembourg is heavily influenced by cross-border purchases from neighboring countries, and Sweden, where *Snus* is one of the most popular products, is not authorized in the E.U.

The estimation equation takes the form:

$$CC_{i,t} \equiv \beta_0 + \beta_1 \cdot D_i + \beta_2 \cdot post_t + \beta_3 \cdot (D_i \times post_t) + u_{i,t}. \quad (1)$$

$CC_{i,t}$ is the combustible consumption in country i in year t . The data for the combustible consumption used are the "Releases for consumption of cigarettes and fine cut tobacco" from the European commission¹¹ from 2010 to 2021. D_i is a dummy variable indicating Poland and $post_t$ a dummy variable indicating the years 2020 and

¹¹ Consumption volumes of fine cut are converted to stick equivalents and summed with consumption volumes of cigarettes. A weight of 0.67 g per stick equivalent is used to convert fine cut.

later. Hence, β_3 measures the effect of introducing the e-cigarette tax on combustible volumes.

From 2010 to 2019, the years preceding the tax increase in Poland, consumption values in both countries showed no discernible trend. A Mann-Kendall test (Libiseller and Grimvall 2002; Mann 1945) conducted for each of the examined countries indicates an insignificant increase in Spain of $\tau = 0.022$ units per capita per year, while in Poland, the τ value was 0.15. The p -values, at 0.59 for Poland and approximately 1 for Spain, are clearly above the threshold for statistical significance. A similar pattern emerges when calculating Sen's slope (Sen 1968) for the same period. For both countries, the confidence intervals span negative as well as positive values. Therefore, we infer that both countries experienced a comparably flat development during the period from 2010 to 2019.

To strengthen confidence in our findings, we also verify the parallel trends assumption by conducting a placebo test (Mora and Reggio 2017). In this test, we re-estimate the DiD model seven times, each time assuming that the treatment (i.e. the introduction of the e-cigarette tax) occurred in a distinct year prior to 2020. If these regressions reveal a significant treatment effect, it could indicate a violation of the parallel trends assumption. However, across all regressions, the corresponding coefficients are not statistically significant at the 1 % level, unlike the treatment effect in the original DiD analysis. This suggests that the parallel trends assumption cannot be rejected.¹²

In 2020, volumes in Spain started to stagnate, whereas the volumes in Poland continued to rise. This observation indicates that, indeed, e-cigarette taxes might have increased the combustible volumes in Poland. Table 2 presents the regression results. The coefficient of the interaction ($D_i \times post_t$) is positive and significantly different from zero at a 1 % significance level. The confidence interval lies entirely beyond the null line, even when allowing only a 0.1 % margin of error. When calculating the standard error, we accounted for potential biases due to serial correlation (Bertrand, Duflo, and Mullainathan 2004) using autocorrelation-consistent standard errors (Driscoll and Kraay 1998).

This estimation result shows that the introduction of the e-cigarette tax in 2020 has increased the consumption of combustibles in Poland. Hence, this brief case study underlines the findings from the previous paragraphs: combustible products and e-cigarettes are indeed substitutes.

¹² We re-estimated the difference-in-differences model seven times, assuming that the tax increase occurred in 2013, 2014, 2015, 2016, 2017, 2018, and 2019, respectively. The estimations were performed using the same sample as in the original analysis. The detailed results of the placebo test can be found in C.

Table 2: Difference-in-differences regression results.

	Consumption [in billion sticks]
(Intercept)	8.9692*** (0.2007)
post _t	0.3614* (0.2009)
D _i	-4.4918*** (0.5460)
D _i × post _t	1.8910*** (0.5603)

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

This chapter has presented various pieces of empirical evidence indicating that NCAs and combustibles are substitutes. The next chapter transitions from empirical analysis to theory, establishing the theoretical foundation for understanding how taxation in the tobacco market influences the demand for combustibles and NCAs.

6 Optimal Taxation of Unhealthy Products

Higher taxation is considered a critical measure by authorities to reduce smoking behavior, as outlined in initiatives such as the *Europe's Beating Cancer Plan*. However, the impact of taxation varies among citizens. It is reasonable to assume that combustible smokers exhibit three response groups when faced with tax increases, which are not necessarily mutually exclusive. One group may be price-inelastic and willing to accept higher prices for smoking, another group might quit or reduce consumption, and a third group may opt to substitute combustibles with NCAs. The challenge in revising the Directive is to adjust minimum taxes to encourage more individuals to fall into the second group at the expense of the first group without undermining the incentives of the third group.

In general, tax increases lead to tax-induced price increases,¹³ and the apparent impact is measured by the own-price elasticity of demand.¹⁴ An increase in cigarette

13 In tobacco markets, producers mostly pass tax increases on to consumers. Therefore, tax-rate differentials between products on the tobacco market are expected to translate into price differentials between these products. For example, European Commission et al. (2020) calculate that 0.7 of the tax increase is passed on to prices (EU-27 average). For the U.S. (2013–2019), Cotti et al. (2022) find that 91 % of e-cigarette taxes are passed on to consumer prices.

14 A critical effect of tax setting derives from the distributional impact of tobacco taxes. If low-income earners smoke over-proportionally, higher taxes on smoking products can exacerbate more dispersion of disposable income across citizens. For simplicity, we will neglect the distributional effects for the ongoing.

prices usually reduces the demand for cigarettes.¹⁵ Besides the effect of tax increases on the product itself, tax increases also affect substitutes and complements of the affected product (see above).

The challenge lies in navigating the interplay between own- and cross-price elasticities. When taxes on less harmful products increase, the negative own-price elasticity makes them less attractive, limiting their market diffusion. Simultaneously, suppose smokers are deterred from switching to less harmful alternatives due to heavier taxation on the latter (positive cross-price elasticity). In that case, it poses a significant challenge in achieving the desired public health outcomes. Balancing these factors is crucial for effective tobacco taxation policies.

The theory of optimal taxation addresses the obstacles associated with these issues, which aims to determine the most effective tax policies to maximize societal welfare. Unlike traditional tax theory, which focuses on utility maximization subject to revenue generation, optimal taxation in health policy aims to maximize welfare by reducing harm to a targeted level. In Appendix D, we present a formalized model within an optimal taxation framework to delve further into these considerations. A similar framework has recently been presented in this journal by Prieger (2023).

The E.U. aims to protect public health by reducing smoking prevalence. Using the smoking prevalence as a measure for public health only captures health effects due to the consumption of combustibles. It treats switching from combustibles to an e-cigarette as equal to quitting. We argue that a comprehensive measure can better represent policy goals. We introduce this measure as society's harm level \mathcal{H} . It depends on the harm-level scores provided, e.g. by Nutt et al. (2014) for different (n) products on the tobacco market. The measure is given by

$$\mathcal{H} \equiv \sum_{i=1}^n h_i \cdot x_i. \quad (2)$$

We argue that \mathcal{H} is a better target than the widely-used smoking prevalence. The main reason is that \mathcal{H} considers that less-harming products *are* harmful nevertheless. Thus, \mathcal{H} seems more appropriate to describe the E.U. commission's policy goal to protect public health since the harm caused by non-combustible alternatives is also reflected.

Considering the distinct harm levels associated with various products, along with the consideration of own- and cross-price elasticities, leads to the derivation of a vector of optimal tax rates, contingent on the aforementioned variables. Optimality is defined by the first-order condition, aligning with standard economic theory, where wealth maximization is subject to a predefined health level set by the government. The detailed derivation of the first-order condition is presented in Eq. (8) in Appendix D. This chapter

¹⁵ For empirical evidence in European countries (Spain, Italy), see Fernández et al. (2004); Gallet and List (2003).

constrains its analysis to illustrative cases, emphasizing exceptions due to assumed negligible elasticities. The exceptional cases are not employed to articulate concrete policy implications but enhance our understanding of the workings of an optimal tax within our framework. For the sake of simplicity, we consider a scenario involving only two goods denoted as k, i , with k representing non-combustible alternatives (NCAs) and i representing combustibles.

1. In the case of zero cross-price elasticity ($\eta_{i,k} = 0$), the optimal tax imposed on product k is positively dependent on its harm level, h_k , when the own-price elasticity ϵ_k is negative. This implies that higher harm levels of product k correspond to higher optimal taxes. The magnitude of this effect is further accentuated with an increasing own-price elasticity ($\epsilon_k \downarrow$). This can be deduced directly from $\frac{\partial t_k^*}{\partial h_k} = -\frac{\lambda}{\mu} \epsilon_k > 0$. In the unlikely scenario where the own-price elasticity is positive, taxes would be negatively correlated with increasing harm level, h_k . This situation is not observed in tobacco markets, based on current evidence.
2. If both elasticities are zero, there is no health-policy rationale for taxing NCAs. This distinction from classical optimal tax theory is apparent. In the context of an exogenously set tax revenue goal, $\epsilon_k = 0$ implies a high tax rate. This is because entirely inelastic demands can be taxed without incurring excess burden due to substitution effects.
3. Consider a scenario where only the demand x_k (NCA) is entirely inelastic ($\epsilon_k = 0$), while $\eta_{i,k} > 0$. In this case, imposing or raising taxes on NCAs would increase combustible demand, contradicting the government's health objectives. If combustibles have a dominant market share ($x_i/x_k > 1$) and pose the highest health threat ($h_i = h_{\max}$), the optimal tax on NCAs would be negative. In this extreme hypothetical scenario, they should be negatively taxed (subsidized) instead of raising NCA prices to discourage NCA users from switching to cigarettes.

In practice, none of the elasticities can be assumed to be zero. Determining the optimal tax rate for any product necessitates a comprehensive consideration of various factors, including the products' distinct impacts on health, market share, and elasticities. Specifically, in scenarios involving more than two products, the optimal tax for any product becomes contingent on the cumulative cross-price effects with all other products. This implies that tax-setting endeavors, driven by health objectives, must consider the existing substitutive relationships among the products in question. Drawing from our empirical findings, we derive a policy recommendation that extends beyond the prescription to tax combustibles at higher rates. It advocates for a sufficiently substantial tax wedge between combustibles and NCAs. Failing to establish an adequate tax differential between combustibles and NCAs may result in tax policies within the tobacco market conflicting with the intended goal of promoting smoking cessation.

7 Conclusions

We echo the European Commission's perspective on the necessity of revising the Tax Directive. However, prior to drafting the revision, it is imperative for policymakers to comprehend the intricate interactions among different tobacco products. Our findings strongly suggest that combustibles and NCAs exhibit substitutive characteristics. Given the widely accepted premise that NCAs pose lesser harm, establishing a significant tax differential between combustibles and NCAs becomes paramount. A judiciously structured tax on NCAs should be set at lower rates to incentivize the transition from combustibles to NCAs and mitigate the risk of reverting to combustibles.

Our analysis reveals notable gender-specific variations in the responsiveness to European tobacco control policies. The current regulatory measures appear to be more effective in reducing smoking prevalence among males, while the impact on female smokers appears weak. The attainment of health-policy objectives outlined by the European Commission may face significant challenges unless the regulatory framework is tailored to engage the female population more effectively. The distinct gender differences underscore the imperative for research and developing gender-specific measures. However, we must emphasize with some limitations that gender-specific data was unavailable for all analyses.

Our policy recommendations are underscored by the European Commission's explicit goal to achieve a smoking prevalence below five percent by 2040. However, the feasibility of this target appears challenging, considering the current tobacco use prevalence of around 25 %. The proposed reduction implies an ambitious 80 % decrease over approximately 20 years. From 2007 to 2018, Europe witnessed a decline in smoking prevalence by 13.4 % (−3.94 percentage points), reflecting an average annual reduction of 1.3 % (geometric mean). This notable reduction was achieved by implementing impactful measures such as mandatory smoke-free areas, advertisement bans, and graphic warnings on product packaging. If we extrapolate this recent decline rate to 2040, the projected smoking prevalence would be approximately 19 %. Achieving the 5 % target by 2040 necessitates a substantial acceleration in the annual decline rate to around 7.1 % on average. To address this, the European Commission has introduced a comprehensive set of new measures, although they are yet to be fully implemented. However, it's crucial to note that even if these measures prove effective, small increases in taxes on NCAs could potentially counteract the positive impact of the proposed package.

In 2025, the E.U. is set to reassess its policies and tax regulations. E.U. authorities should allocate resources for additional research to quantify the pertinent parameters for formulating a well-informed tax and tobacco control policy. Meanwhile, the United Kingdom has embarked on a novel initiative to curb smoking rates. E-cigarettes are now prescribable by England's National Health Service (NHS). Manufacturers of

e-cigarettes are eligible to seek approval from the U.K.'s Healthcare Agency. The effectiveness of this approach in comparison to the E.U.'s existing measures remains uncertain and warrants observation.

Moreover, the notorious use of the smoking prevalence concept, which does not differentiate between quitting and switching, underscores the need to explore broader public health metrics. In this regard, we introduced a simple example of such a measure. The E.U. strategy appears to lack the depth of research required as a decision-making tool. The notable distinctions in data and research availability compared to the U.S. should not breed complacency but serve as a clarion call for action. This paper contributes evidence that merits consideration in shaping a new tax environment for the European tobacco market.

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A WHO Prevalence Estimates

Table 3: WHO prevalence estimates (2018) for the U.S. and selected European countries.

Country	Cig. smoking	Tob. smoking	Tob. use
USA	17.1	20.0	25.1
Germany	26.0	28.0	28.0
France	31.5	34.6	34.6
Italy	23.4	23.4	22.8
Spain	25.9	27.9	27.9
Poland	24.3	26.0	26.0
Sweden	16.9	28.8	12.4
Portugal	24.8	27.9	27.9
Croatia	33.1	36.6	36.6

B Female Smoking Rates 2000 – 2028 by Country

The table provides the smoking prevalence rates for women in the 27 EU member states. The respective values for 2020 are partly estimates by the WHO, based on surveys from the previous year or earlier years. For better clarity, we have added a column named "Trend." It indicates how the values have changed since 2010. A ↓ indicates a reduction of more than one percentage point, a ↘ indicates a small change (of less than one percentage point). For such small changes, statistical errors regarding the sign cannot be ruled out. Significant increases are marked with an ↑, Stagnation (± 0.1 percentage point) by →.

Table 4: Female smoking prevalence in European countries 2000–2020. Data: World Health Organisation, GHO.

Country	2000	2005	2007	2010	2015	2020	Trend
AUT	47.1	40.5	38.0	34.6	29.8	25.5	↓
BEL	23.0	22.6	22.6	22.5	22.2	22.0	↘
BGR	35.7	36.0	36.4	36.6	37.4	38.1	↑
CYP	21.1	21.7	21.8	22.0	22.9	23.6	↑
CZE	28.4	27.8	27.8	27.4	27.1	26.8	↘
DEU	31.6	28.3	27.0	25.3	22.6	20.2	↓
DNK	34.7	29.1	27.1	24.4	20.5	17.2	↓
ESP	27.6	27.6	27.6	27.6	27.5	27.5	→
EST	27.3	25.8	25.3	24.5	23.2	21.8	↓
FIN	23.8	21.8	21.0	19.8	18.1	16.5	↓
FRA	30.1	30.8	31.2	31.6	32.5	33.3	↑
GRC	44.4	40.5	39.0	37.0	34.0	31.5	↓
HRV	27.5	29.4	30.3	31.6	33.8	36.2	↑
HUN	31.9	30.8	30.5	29.9	29.1	28.5	↘
IRL	36.3	30.4	28.4	25.7	21.5	18.2	↓
ITA	19.2	19.3	19.2	19.2	19.2	19.2	→
LTU	20.2	20.1	19.9	19.9	19.8	19.6	↘
LUX	24.6	23.9	23.7	23.1	22.5	21.9	↓
LVA	25.8	24.2	23.5	22.8	21.3	20.0	↓
MLT	24.5	24.2	23.9	23.9	23.4	23.3	↘
NLD	31.8	28.0	27.0	25.1	22.5	19.9	↓
POL	31.7	28.5	27.3	25.7	23.2	20.9	↓
PRT	15.2	16.3	16.8	17.5	18.8	20.3	↑
ROU	25.5	24.1	23.6	22.9	21.8	20.7	↓
SVK	20.7	22.0	22.8	23.7	25.5	27.6	↑
SVN	23.1	22.0	21.5	20.9	19.9	18.9	↓
SWE	35.7	27.8	25.1	21.7	16.9	13.1	↓

Bulgaria, Cyprus, France, Portugal, Slovenia, and Croatia have rising prevalence rates. Therefore, the phenomenon of increasing prevalence is not only observed in Eastern or Western Europe. In some countries, we observe stagnation or a slight decrease in rates over the past decade. These include Spain, Belgium, the Czech Republic, Hungary, Italy, Lithuania, and Malta.

C Results of the Placebo Tests

Table 5: Difference-in-differences regression results for various treatment start years.

	2013	2014	2015	2016	2017	2018	2019
Intercept	8.701 (0.420)	9.124 (0.530)	9.098 (0.413)	9.084 (0.340)	9.055 (0.294)	8.993 (0.277)	8.964 (0.255)
post _t	0.4369 (0.4077)	-0.1417 (0.5400)	-0.1179 (0.4289)	-0.1098 (0.3682)	-0.0618 (0.3255)	0.1101 (0.2835)	0.2620 (0.2535)
D_i	-3.630 (0.819)	-4.488 (1.056)	-4.715 (0.961)	-4.826 (0.843)	-4.852 (0.726)	-4.732 (0.647)	-4.616 (0.607)
$D_i \times \text{post}_t$	-0.7285 (0.8811)	0.4670 (1.0085)	0.9221 (0.9536)	1.2987 (0.8742)	1.6206 (0.7625)	1.6685 (0.7001)	1.7594 (0.6511)

Bold typed estimators indicate $p < 0.01$.

D An Optimal-Taxation Approach on Tobacco Market

In the following, we will illustrate how optimal taxation can be modeled for the government's target to reach a set society's harm level, denoted by \mathcal{H} . We denote by h_i the harm level associated with tobacco product i , $i \in \{1, \dots, n\}$.¹⁶ One can think of the harm-level scores provided by, e.g. Nutt et al. (2014) for different products on the tobacco market. Society's harm level is given by

$$\mathcal{H} \equiv \sum_{i=1}^n h_i \cdot x_i. \quad (3)$$

The E.U. aims to protect public health by reducing smoking prevalence. Using the smoking prevalence as a measure for public health only captures health effects due to the consumption of combustibles. It treats switching from combustibles to

¹⁶ For simplicity, the term *tobacco product* is used in the following for all combustible tobacco products and their non-combustible alternatives. Note that \mathcal{H} denotes the politically set health level of the society. The actual level is denoted by \mathcal{H} .

an e-cigarette as equal to quitting. We argue that \mathcal{H} is a better target than the widely-used smoking prevalence. The main reason is that \mathcal{H} considers that less-harming products *are* harmful nevertheless. Thus, \mathcal{H} seems more appropriate to describe the E.U. commission's policy goal to protect public health since the harm caused by non-combustible alternatives is also reflected.

The demand for tobacco products depends on prices and how consumers respond to them, such that $x_i = x_i(\vec{p})$, where \vec{p} denotes the price vector. Thus, the demand for a particular tobacco product, x_k ($k \in \{1, \dots, n\}$) depends on its own price, p_k , and on the other products' prices p_i , $i \in \{1, \dots, n\} \setminus \{k\}$. The consumer prices comprise the producer prices (\vec{q}) and the respective tax (\vec{t}). The government is interested in the price level on the market that leads to a politically set health level $\tilde{\mathcal{H}} < \mathcal{H}$. The latter expression denotes that the targeted harm level is below the current one (hence, the health level after the tax setting is better than in the initial situation).¹⁷

A government's optimization problem may be formulated in terms of the Lagrangian:

$$\mathcal{L}(\cdot) = V(\vec{p}, e) - \lambda \left[\sum_i h_i \cdot x_i(\vec{p}) - \tilde{\mathcal{H}} \right]. \quad (4)$$

$V(\cdot)$ denotes the indirect utility function, which we use in line with existing literature as a measure for welfare. The derivative with respect to the tax rate of a particular tobacco product $k \in \{1, \dots, n\}$ yields

$$\frac{\partial \mathcal{L}}{\partial t_k} = -\mu \cdot x_k - \lambda \cdot \sum_i h_i \frac{\partial x_i}{\partial p_k} = 0. \quad (5)$$

We make use of *Roy's identity*¹⁸ ($\partial V / \partial t_k = -\mu \cdot x_k$), where μ denotes the marginal utility of income to the consumer. The first-order condition (5) can be rewritten to

$$\sum_{i=1}^n h_i \frac{\partial x_i}{\partial p_k} = -\frac{\mu}{\lambda} x_k. \quad (6)$$

The left-hand side of the rearranged first-order condition (6) describes consumers' responsiveness to price changes. In order to make the term more interpretable (and accessible for econometric estimates), we split it into an own-price and a cross-price elasticity. The latter is defined as $\eta_{j,k} = \partial x_j / \partial p_k \cdot p_k / x_j$. The own-price elasticity, on the

¹⁷ The assumption $\tilde{\mathcal{H}} < \mathcal{H}$ is crucial since otherwise, all effects derived in this section would reverse. The reason is that if $\tilde{\mathcal{H}} > \mathcal{H}$, then society would be healthier in the initial situation, and the government would aim to increase society's health hazard.

¹⁸ For an overview of optimal taxation and the properties of the indirect utility function (envelope theorem) see Atkinson and Stiglitz (2015, Ch. 12-2).

other hand, yields $\epsilon_j = \partial x_j / \partial p_j \cdot p_j / x_j$. By using the elasticity terms, we can rewrite the first-order condition to

$$\epsilon_k \cdot h_k \cdot x_k + \sum_{i \neq k} \eta_{i,k} \cdot h_i \cdot x_i = -\frac{\mu}{\lambda} x_k \cdot p_k. \quad (7)$$

The first term denotes the harm level of the targeted good, weighted by its own price elasticity. The second term denotes the summed harm level of all other products, weighted by the sum of their cross-price effects. Dividing both sides of Eq. (7) by x_k/p_k yields – after some straightforward rearrangements – the optimal tax level t_k^* (necessary condition) for product x_k .

$$t_k^* = -\frac{\lambda}{\mu} \left[h_k \cdot \epsilon_k + \sum_{i \neq k} \eta_{i,k} \cdot h_i \cdot \frac{x_i}{x_k} \right] - q_k. \quad (8)$$

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