Impact of cigarette prices and age-of-sale policies on smoking prevalence among youth in 26 European Member States (2012–2023): a longitudinal ecological study using repeated cross-sectional data

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Summary

Background Reducing tobacco and nicotine use and preventing smoking initiation among youth are key public health priorities. We evaluated the impact of cigarette prices and age-of-sale laws on youth smoking prevalence in the European Union (EU).

Methods In this ecological study with 26 EU Member States as the unit of analysis, we estimated smoking prevalence among individuals aged 15–24, using five Eurobarometer waves (2012–2023, n = 12,087). We used fixed-effects panel regression models to assess the association between cigarette prices, the introduction of 18+ age-of-sale laws for tobacco products and changes in youth smoking prevalence, controlling for time and tobacco control policy implementation.

Findings Weighted youth smoking prevalence decreased from 28.4% (841/2818) in 2012 to 22.2% (490/2222) in 2023, although the trend was not consistently downward. A €1 increase in inflation-adjusted cigarette prices per pack was associated with a 3.4 percentage point reduction in male youth prevalence (95% CI: −6.40 to −0.45), while there was no significant association for females or at the EU level. Regional variation was observed, with price increases associated with substantial reductions in youth smoking among both sexes in Southern Europe and among males in Northern Europe. In contrast, no such associations were found in Western or Eastern Europe. Age-of-sale laws were not significantly associated with youth smoking prevalence at the EU level.

Interpretation Current taxation and age-of-sale policies remain insufficient, with impacts varying by sex and region. Achieving the tobacco endgame requires harmonised EU-level measures and stronger enforcement, particularly of these two policies, to prevent the ongoing influx of new youth smoking initiates. This study suggests that their potential impact has been constrained by inadequate enforcement to date rather than by policy ineffectiveness.

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Keywords: Youth tobacco use; Tobacco control; Prevention; Price; Age-of-sale policies

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Research in context

Evidence before this study

In the European Union (EU), 93% of the people who smoke establish regular smoking by the age of 25. Therefore, ensuring that youth remain smoke-free through their mid-twenties is a public health priority to reduce the burden of smoking in the next generation. To identify studies that evaluated the impact of cigarette prices through taxation and age-of-sale laws on tobacco use among youth, we searched PubMed for articles published between the database inception and September 1, 2025. We used the search terms ("smoking" OR "tobacco use" OR "initiation") AND ("tobacco price" OR "tax policy" OR "age-of-sale law" OR "age-of-sale policy") AND ("young people" OR "youth" OR "adolescent") AND English [Language]. Although comprehensive tobacco control policies, such as taxation and age-of-sale laws, are widely recommended, their population-level impact on youth smoking behaviour across EU countries remains unclear.

Added value of this study

To our knowledge, this is the first EU-wide study to longitudinally assess the association between cigarette prices, age-of-sale laws, and youth smoking behaviour using harmonised cross-country data. By integrating nationally representative surveys conducted with consistent methodology over the past decade, this study provides the most comprehensive analysis to date of temporal, regional, and national trends in youth smoking prevalence across all EU countries. Our findings offer timely and policy-relevant evidence to support stronger youth-focused tobacco control strategies and help address existing gaps in youth smoking prevention, in line with the tobacco endgame strategies.

Implications of all the available evidence

Despite an overall decline in youth smoking prevalence in the EU, approximately one in five individuals aged 15 to 24, an estimated 10.4 million people, still smoked in 2023, a figure considerably higher than in other global regions. This life stage is a critical period for shaping long-term smoking behaviours. Our findings suggest that current taxation and age-of-sale laws may not be sufficient to reduce youth smoking to the levels needed to achieve tobacco endgame by 2040. To succeed, the EU must strengthen the enforcement of current policies and expand the implementation of comprehensive tobacco control measures, with particular attention to addressing differences by sex and region. A strong emphasis should be placed on preventing both the initiation and continuation of smoking among young people. Our nuanced findings may also inform assessments of these measures in other global regions at earlier stages of the tobacco epidemic.

Introduction

Tobacco use remains one of the leading preventable causes of death and disease in the European Union (EU), contributing substantially to lung cancer, cardiovascular disease, and other chronic conditions.[1] Despite decades of tobacco control efforts in the EU, nearly a quarter of adults (24%) were estimated to smoke tobacco currently, 28% of males and 21% of females in 2023, and the associated health and economic burdens remain immense.[2] The EU aims to reduce tobacco use to below 5% by 2040, in line with its Tobacco-Free Generation goal, which aligns with the tobacco endgame approach.[3] This approach shifts the focus from controlling the tobacco epidemic to ending it by reducing use to minimal levels. A recent modelling study estimated that achieving a tobacco-free generation by eliminating smoking among individuals born between 2006 and 2010 could prevent approximately 148,600 (70.1%) of lung cancer deaths in males and 131,900 (72.2%) in females in Europe, among the highest avoidable burdens globally.[4]

The initiation and development of smoking occurs predominantly during a relatively narrow age window spanning adolescence and young adulthood (ages 15–24), and individuals who remain smoke-free through their mid-20s are unlikely to begin smoking thereafter.[5] In the EU, recent estimates show that 93% of people who smoke establish regular smoking by the age of 25; thus, this period is considered a key intervention target for smoking prevention efforts.[2] An earlier age of initiation increases vulnerability to nicotine addiction and elevates the burden of smoking-related diseases later in life, as health risks associated with smoking rise with cumulative exposure.[6,7] Individuals who begin smoking at a younger age are more likely to develop nicotine dependence, progress to daily smoking, continue the consumption into adulthood, and ultimately become heavier tobacco users.[8,9]

Robust evidence supports the effectiveness of comprehensive tobacco control policies in reducing tobacco use, with increased taxation as one of the most cost-effective measures, especially for youth, who are more sensitive to price changes.[10–12] Despite the Tobacco Taxation Directive 2011/64/EU, which sets harmonised minimum excise tax rates for manufactured cigarettes, large disparities in cigarette prices persist across EU countries.[13] In addition, all EU countries have implemented a minimum legal tobacco purchase age of 18 years, as required by Article 16 of the World Health Organization Framework Convention on Tobacco Control (WHO FCTC) as of 2025; nonetheless, the timing and enforcement vary widely. Notably, Ireland has approved legislation to raise the minimum age further to 21, with implementation expected in

2028.[14] These policies are internationally recommended as key tools to reduce youth smoking,[10–12,15] but their long-term impact on youth smoking in the EU context remains underexplored. Existing evidence has primarily focused on adult populations, national-level assessments, or relied on composite indicators such as the score of the price component of the Tobacco Control Scale, rather than directly evaluating cigarette prices.[16–19] Therefore, this study examines patterns of youth smoking prevalence in the EU and assesses the impact of cigarette prices and 18+ age-of-sale laws on changes in youth smoking.

Methods

Study design and data sources

We analysed publicly available, repeated cross-sectional data from the Special Eurobarometer surveys on tobacco (2012–2023), conducted by the European Commission and nationally representative of individuals aged ≥15 years in each EU country. Most countries include around 1000 respondents, except for some countries such as Cyprus, Luxembourg, and Malta, which include approximately 500 respondents.

Eurobarometer surveys employ a standardised multi-stage random sampling method, with Primary Sampling Units (PSUs) selected proportionally to population size and density. This approach covers all Eurostat NUTS II regional classifications, as well as metropolitan, urban, and rural areas. Within each PSU, starting addresses were randomly selected, and subsequent addresses were chosen systematically. In each household, one individual aged ≥15 years with the nearest birthday to the interview date was interviewed in the national language. All data were self-reported. Although response rates are unpublished except for 2023, post-stratification weights from Eurostat ensure national and EU-level representativeness in terms of age, sex, and area of residence.[2,20–23]

We conducted an ecological study across 26 EU countries (EU26), excluding Croatia (not yet an EU Member State in 2012) and the United Kingdom (which left the EU in 2021). This analysis was restricted to individuals aged 15–24 years from the five Eurobarometer waves: wave 77.1 (n = 2,818, February–March 2012), wave 82.4 (n = 2,484, November–December 2014), wave 87.1 (n = 2,199, March 2017), wave 93.2 (n = 2,304, August–September 2020), and wave 99.3 (n = 2,282, May–June 2023). In total, the final sample included 12,087 youth respondents across 26 countries and five time points.[20–23] While data were collected at the individual level, all analyses were conducted at the country level, with variables aggregated to reflect national trends.

Variables

Current cigarette smoking

Smoking prevalence among individuals aged 15–24 years (hereafter referred to as "youth smoking prevalence") was computed (number of current smokers aged 15–24 years over total number of individuals aged 15–24 years) based on responses to the question: "*Regarding smoking cigarettes, cigars, cigarillos, or a pipe, which of the following applies to you?*". Respondents who reported "You currently smoke" were defined as current smokers. The question wording and response format were consistent across all survey waves, allowing for a reliable assessment of current cigarette smoking over the study period.[24]

Price of manufactured cigarettes

Data on the price of box cigarettes (also known as manufactured cigarettes) were obtained from the European Commission's Excise Duty Tables report. We collected Weighted Average Price (WAP) data for each country for the years 2012, 2014, 2017, 2020 and 2023. WAP for cigarettes is calculated as the total retail value of all cigarettes released for consumption, including all taxes, divided by the total quantity of cigarettes released in the preceding calendar year. While WAP is originally reported per 1000 cigarettes, we converted it to the price per standard pack of 20 cigarettes, expressed in euros (€). To account for inflation, we converted nominal WAP into real prices using the Harmonised Index of Consumer Prices (HICP) from Eurostat. Real prices (hereafter referred to as "cigarette price") were calculated for each year based on the HICP (2015 = 100) as the reference. We used the price of manufactured cigarettes as the primary indicator, as comparable roll-your-own tobacco data were available for only 11 countries during the study period. Manufactured cigarettes account for over 80% of the EU tobacco sales market, compared to around 11% for roll-your-own tobacco.[25]

National 18+ age-of-sale laws across the EU

Information on national age-of-sale laws for tobacco products was obtained through a structured review of publicly available government and policy documents retrieved from official websites and online databases. The enactment year of laws raising the minimum legal age for tobacco sales to 18 years was coded as a binary variable (yes/no), indicating whether an 18+ age-of-sale law was in force during each survey year.

Tobacco control policy implementation level

The Tobacco Control Scale (TCS; www.tobaccocontrolscale.org) is an expert-developed tool designed to systematically monitor the implementation of national tobacco control policies. It includes six components: price (30 points), smoke-free laws (22 points), public spending per capita on tobacco control (15 points), bans on tobacco advertising, promotion and sponsorship (TAPS) (13 points), health warnings (10 points) and cessation treatment (10 points). The total score ranges from 0 to 100, with higher scores

reflecting stronger policy implementation across these domains. For each survey year, we used the TCS scores from the most recent report available prior to that year: specifically, the reports from 2010, 2013, 2016, 2019 and 2021 as available on the TCS website. We included all TCS components except for the price component to measure tobacco control policy progress in each country. Since the TCS price component is based on WAP, it was excluded to avoid multicollinearity and to ensure that cigarette prices and the TCS score captured distinct dimensions of tobacco control.

Gross domestic product per capita

We obtained real gross domestic product (GDP) per capita for the years 2012, 2014, 2017, 2020 and 2023 from Eurostat, as a measure of each country's socioeconomic conditions. Real GDP per capita represents the total value of goods and services produced within a country, adjusted for inflation, divided by the average population in a given year. It provides a more accurate reflection of the average standard of living than nominal GDP per capita, as it takes into account changes in price levels.

Time

Time refers to the calendar year of the survey in which data was extracted (e.g., 2012, 2014, 2017, 2020 and 2023). This variable was treated as a continuous variable allowing the model to estimate the annual trend in youth smoking prevalence.

Region

EU countries were grouped into four sub-regions following the United Nations geoscheme: Northern Europe (Denmark, Ireland, Latvia, Lithuania, Estonia, Finland, Sweden), Western Europe (France, Belgium, Austria, Germany, The Netherlands, Luxembourg), Southern Europe (Greece, Italy, Malta, Portugal, Slovenia, Spain, Cyprus) and Eastern Europe (Slovakia, Czechia, Hungary, Poland, Bulgaria, Romania).

Statistical analyses

We calculated youth smoking prevalence by sex and country for the years 2012, 2014, 2017, 2020 and 2023. An ecological analysis using countries as the unit of analysis was conducted to examine the association between the relative change in cigarette prices (independent variable) and youth smoking prevalence (dependent variable) from 2012 to 2023. We used Spearman's rank correlation coefficients (r_{sp}) and 95% confidence intervals (CIs) to assess the association, overall and stratified by sex. Relative changes in cigarette prices and youth smoking prevalence were calculated as percentages using 2012 as the baseline. Relative changes were used instead of absolute changes to account for baseline differences among countries.

We performed a panel-data fixed-effects linear regression to examine the association between two key independent variables: changes in cigarette prices and the implementation timing of the 18+ minimum legal age-of-sale laws and youth smoking prevalence. Analyses were conducted for the overall population and stratified by sex. The model was adjusted for time to account for underlying temporal trends, as well as for each country's total TCS score. The fixed-effects specification accounts for unobserved, time-invariant factors across countries.[26] The real GDP per capita was excluded from the final models, as it did not improve model fit due to high multicollinearity with cigarette prices.

Given the substantial differences between countries in social, cultural, and policy contexts, as well as their stage in the tobacco epidemic,[27,28] we also conducted a stratified linear mixed-effects regression analysis. Countries were grouped into tertiles based on youth smoking prevalence in the earliest survey year (2012): the lower tertile (bottom 33.3%), middle tertile (33.4–66.6%), and upper tertile (top 33.3%), overall and by sex. Separate models were estimated for each group to assess whether associations between the independent variables (cigarette prices, age-of-sale laws, TCS score, and time) and youth smoking prevalence varied by baseline prevalence. A similar stratified analysis was also performed by geographical region and sex to examine potential regional differences in policy impacts.

A sensitivity analysis was conducted with initiation rates of regular smoking. Smoking initiation rates reflect the proportion of individuals who had started smoking regularly by a given age, providing a complementary perspective on smoking uptake among young people. This analysis was based on estimates from a previous paper,[29] and allowed us to examine whether the associations observed with youth smoking prevalence held when using an alternative indicator of tobacco use behaviour among youth. There were no missing data for the variables included in the analyses. To account for the complex survey design, we applied the weights provided in the official Eurobarometer datasets. All analyses were conducted using R version 4.4.2, except for the regression models, which were performed in STATA version 14.

Role of the funding source

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Results

Patterns in youth smoking prevalence over time

Across the EU, weighted youth smoking prevalence decreased from 28.4% (95% CI: 25.9–31.0%) in 2012 to 22.2% (19.3–25.0%) in 2023 (Fig. 1). Among males, prevalence declined from 33.7% (29.9–37.8%) to 24.3%

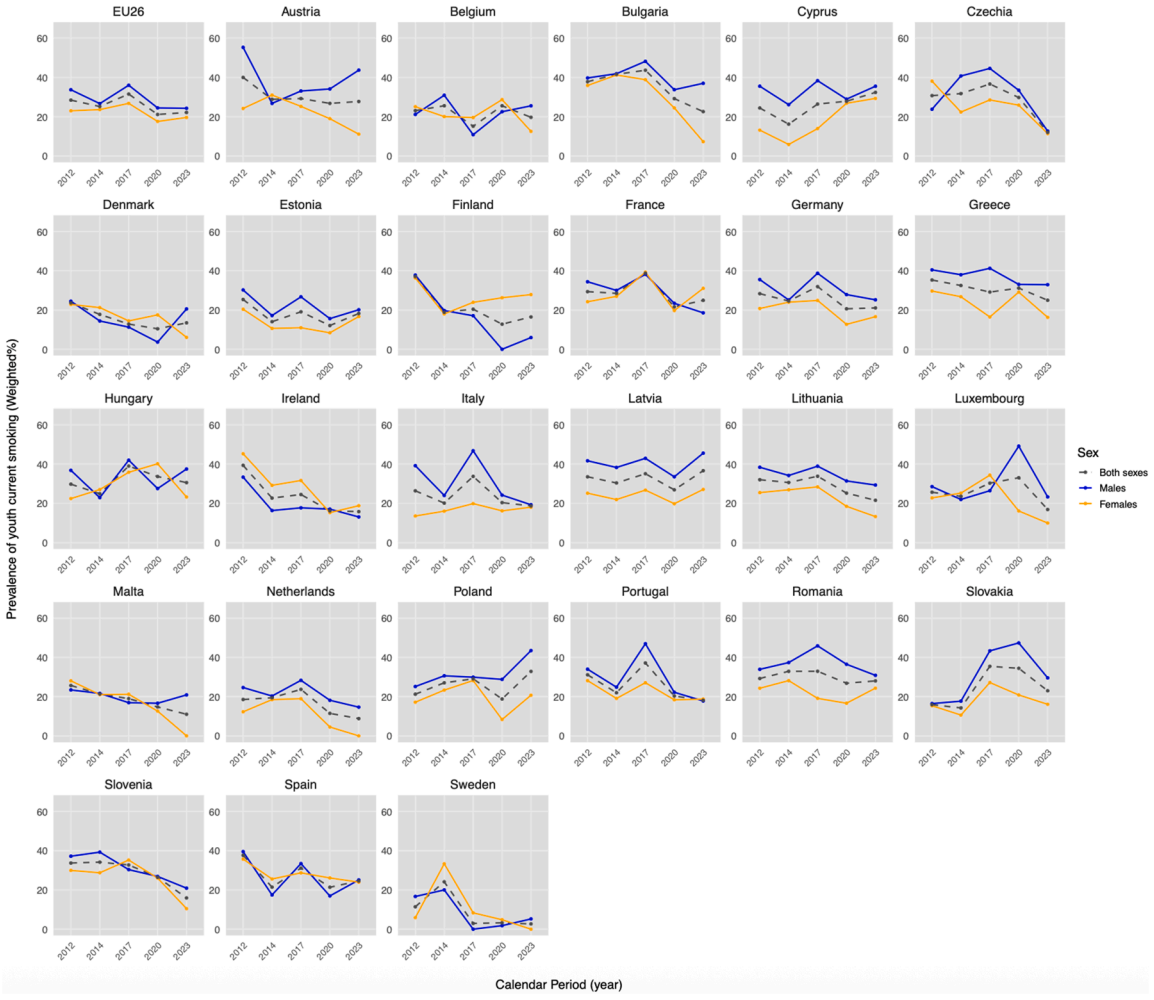

Fig. 1: Time trends of weighted youth smoking prevalence in the 26 European Union Member States (EU26) from 2012 to 2023. Footnote: Youth smoking prevalence was calculated by weighting according to population sizes provided in the official Eurobarometer datasets.

(20.6–28.4%), and among females from 23.0% (20.0–26.4%) to 19.6% (15.8–24.0%) over the same period.

In 2023, youth smoking prevalence varied widely across EU countries, ranging from 2.7% in Sweden to 36.6% in Latvia. Between 2012 and 2023, the overall prevalence of smoking in EU26 decreased by 22.1%, with a larger relative decrease among males (–28.0%) than females (–14.7%). National trends ranged from a relative decrease of 76.6% in Sweden to 4.2% in Romania. In contrast, a relative increase in youth smoking was observed in Hungary, Latvia, Cyprus, Slovakia and Poland, with the largest increase noted in Poland (+54.7%) (Fig. 2).

Introduction of +18 age-sales-laws

Four countries (Poland, Finland, Sweden, and Latvia) enacted 18+ age-of-sale laws before 2000. Between 2001 and 2010, 12 countries enacted them, and a further 10 countries did so by 2019, with Belgium and Austria being the latest adopters in 2019 (Supplementary Figure S1).

Trends in the price of manufactured cigarettes over time

Across the EU, the mean inflation-adjusted price of a 20-cigarette pack increased from €3.8 in 2012 to €4.8 in 2023 (2015 as base year). In most countries, growth in cigarette prices stagnated during the study period, except in Denmark, Finland, France, and Ireland, where substantial price increases were recorded. Prices varied considerably across countries in 2023, ranging from €2.2 in Bulgaria to €12.9 in Ireland (Supplementary Figures S2).

Correlation between cigarette prices and youth smoking prevalence

At the ecological level, we examined the association between the relative change in cigarette prices and the

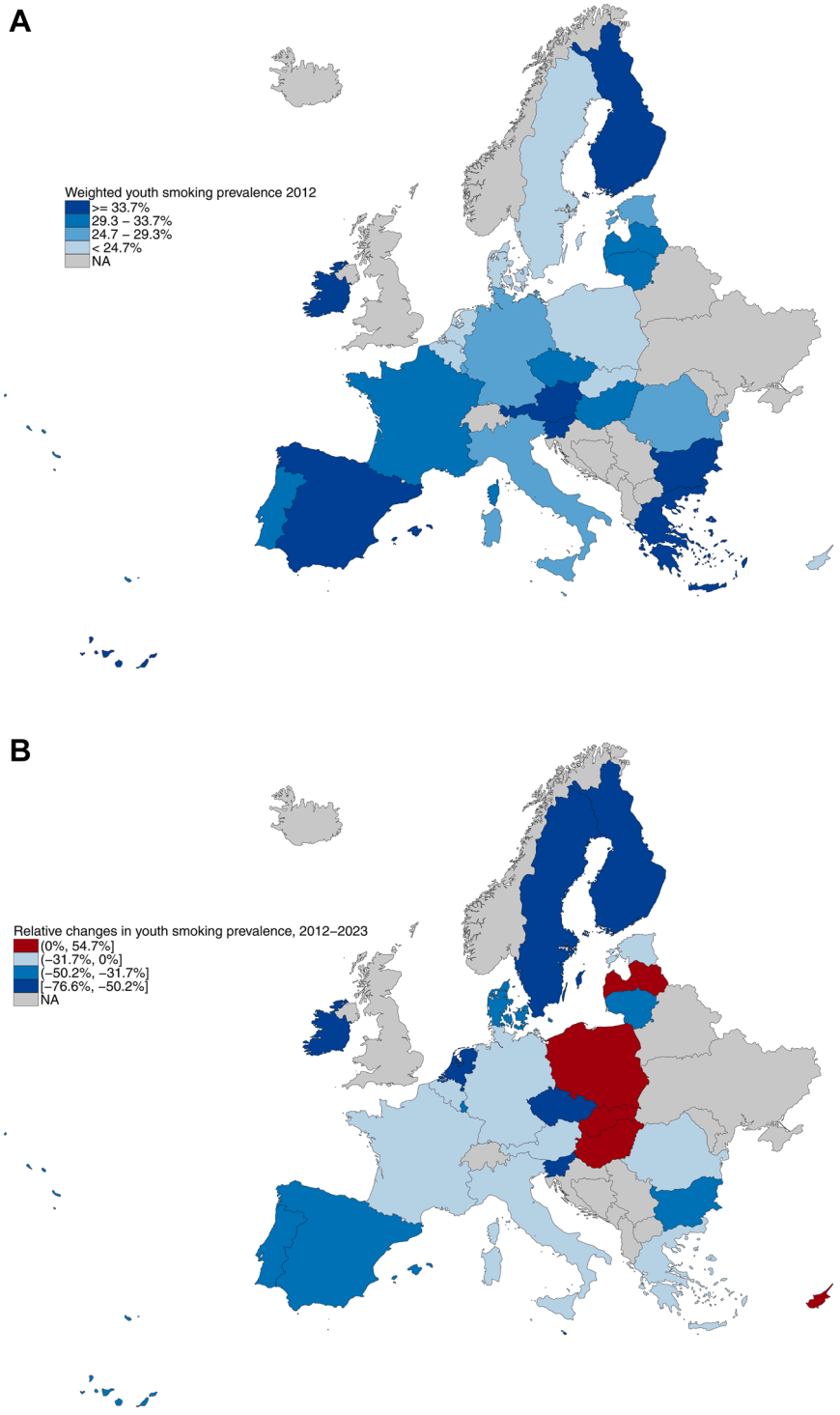

Fig. 2: Weighted youth smoking prevalence in the EU26: (A) Youth smoking prevalence 2012 and (B) Relative changes in youth smoking prevalence 2012–2023.

relative change in youth smoking prevalence between 2012 and 2023. A greater relative increase in cigarette prices was associated with a greater relative decrease in overall youth smoking prevalence (r_{sp} = –0.46, $p < 0.001$). Similar associations were observed for males (r_{sp} = –0.44, $p < 0.001$), while the association for

females did not reach statistical significance (r_{sp} = –0.24, p = 0.084) (Supplementary Figures S3).

In the panel-data regression analysis, each €1 increase in cigarette prices was associated with a 1.69 percentage point decrease in overall youth smoking prevalence, although this association did not reach statistical significance. When stratified by sex, a significant negative association was observed among males (–3.42 percentage points; 95% CI: –6.40 to –0.45), while the association was not significant among females (+0.39 percentage points; –2.12 to 2.90) (Table 1).

Time (calendar year) was significantly associated with youth smoking prevalence: each additional calendar year was associated with a 0.75 percentage point decrease overall (95% CI: –1.28 to –0.23) and a 0.90-point decrease among females (–1.53 to –0.26), with no significant change observed among males. Other policy variables, including the TCS score and age-of-sale laws, were not significantly associated with changes in youth smoking prevalence in any group.

Youth smoking prevalence 1 year change	
All	(N = 130)
Price of cigarettes (per €1 increase per pack)	–1.69 (–3.91 to 0.54)
Tobacco control scale	0.17 (–0.19 to 0.52)
Age-of-sale law	1.22 (–3.30 to 5.74)
Time (per calendar year)	–0.75 (–1.28 to –0.23)*
Males	(N = 130)
Price of cigarettes (per €1 increase per pack)	–3.42 (–6.40 to –0.45)*
Tobacco control scale	0.25 (–0.23 to 0.72)
Age-of-sale law	2.55 (–3.51 to 8.60)
Time (per calendar year)	–0.65 (–1.35 to 0.05)
Females	(N = 130)
Price of cigarettes (per €1 increase per pack)	0.39 (–2.31 to 3.08)
Tobacco control scale	0.06 (–0.36 to 0.49)
Age-of-sale law	–0.13 (–5.61 to 5.35)
Time (per calendar year)	–0.90 (–1.53 to –0.26)*

Footnote: Data are presented as β (95% CI). β coefficients represent the percentage point change in youth smoking prevalence associated with a one-unit increase in the predictor or, in the case of a binary variable such as the age-of-sale law, the change associated with its implementation. Price of cigarettes is expressed as the real (inflation-adjusted) price per 20-cigarette pack (in euros); coefficients correspond to the change in prevalence associated with a €1 increase in the price per pack. *: p < 0.05.

Table 1: **Panel-data linear regression analysis for youth smoking prevalence in relation to the price of cigarettes, the Tobacco Control Scale, the age-of-sale law for tobacco purchase and time (year): overall and sex-stratified.**

Stratified analysis by baseline youth smoking prevalence in 2012

A linear mixed-effects model was performed, stratified by tertiles of country-level youth smoking prevalence in the baseline year (2012): low, moderate, and high prevalence groups (Table 2). No statistically significant association between cigarette prices and youth smoking prevalence was observed in the overall population or among females in any subgroup. In contrast, among males, a €1 increase in cigarette prices was significantly associated with a reduction in youth smoking prevalence across all subgroups: –4.29 percentage points (95% CI: –8.01 to –0.56) in low-prevalence countries, –2.19 (–4.22 to –0.17) in moderate-prevalence countries, and –1.95 (–3.56 to –0.34) in high-prevalence countries.

Time was also significant associated with annual declines in youth smoking prevalence in moderate (β = –1.09, 95% CI: –1.65 to –0.53) and high baseline prevalence countries (β = –0.7; –1.22 to –0.18), particularly among females in both groups (moderate: β = –1.18; –1.84 to –0.52; high: β = –1.35; –1.98 to –0.73). Neither the TCS, nor the 18+ age-of-sale laws showed significant associations with youth smoking prevalence in any subgroup.

Stratified analysis by region

As shown in Table 3, regional variation was observed in the relationship between cigarette prices and youth smoking prevalence. Each €1 rise per pack in cigarette prices was significantly associated with a decrease in youth smoking prevalence in Southern Europe, across all subgroups: overall (β = –7.13, 95% CI: –10.93 to –3.32), males (β = –6.56; –11.80 to –1.32), and females (β = –7.63; –12.34 to –2.93). In Northern Europe, price increases were significantly associated with decreased youth smoking prevalence among males (β = –3.58; –6.77 to –0.39), but no significant associations found for the overall population or females. In contrast, no significant associations were observed in Western or Eastern Europe.

In Eastern Europe, the implementation of the 18+ age-of-sale law was associated with a 15.5-percentage point reduction in youth smoking prevalence among females (95% CI: –27.53 to –0.11), whereas no significant associations were observed in other regions. Time was significantly associated with yearly decline in youth smoking prevalence among females in all regions except for Western Europe, including Northern (β = –1.11; –2.06 to –0.16), Southern (β = –0.91; –1.63 to –0.18), and Eastern Europe (β = –1.20; –2.30 to –0.11). No significant association between time and youth smoking prevalence was observed among males in any region.

Sensitivity analysis showed broadly similar results in both the overall EU panel and subgroup analyses, with minor variations detailed in Supplementary Tables S1–S3.

Discussion

Youth smoking prevalence in the EU declined overall from 2012 to 2023, although an estimated 22.2% of individuals aged 15–24 years continued to smoke in 2023, representing approximately 10.4 million young people. In panel-data analyses, a €1 increase in cigarette prices per pack was associated with reductions in youth

	Countries with low YSP	Countries with moderate YSP	Countries with high YSP
All	N = 45	N = 45	N = 40
Price of cigarettes	−2.68 (−5.53 to 0.17)	−1.44 (−3.10 to 0.23)	−0.85 (−1.78 to 0.09)
Tobacco control scale	0.13 (−0.61 to 0.87)	0.36 (−0.04 to 0.69)	−0.21 (−0.52 to 0.09)
Age-of-sale law	−0.52 (−7.09 to 6.05)	1.16 (−5.75 to 8.06)	−0.79 (−5.60 to 4.01)
Time	−0.14 (−0.98 to 0.70)	−1.09 (−1.65 to −0.53)*	−0.70 (−1.22 to −0.18)*
Males	N = 45	N = 45	N = 40
Price of cigarettes	−4.29 (−8.01 to −0.56)*	−2.19 (−4.22 to −0.17)*	−1.95 (−3.55 to −0.34)*
Tobacco control scale	0.24 (−0.72 to 1.20)	0.29 (−0.13 to 0.71)	−0.49 (−0.99 to 0.02)
Age-of-sale law	−0.57 (−9.12 to 7.97)	−1.74 (−11.6 to 8.09)	2.88 (−4.87 to 10.6)
Time	0.08 (−1.00 to 1.17)	−0.94 (−1.71 to −0.16)*	−0.23 (−1.01 to 0.55)
Females	N = 45	N = 45	N = 40
Price of cigarettes	−0.97 (−3.52 to 1.58)	−0.45 (−2.32 to 1.42)	−0.17 (−1.30 to 0.96)
Tobacco control scale	−0.05 (−0.80 to 0.70)	0.35 (−0.02 to 0.73)	0.23 (−0.14 to 0.59)
Age-of-sale law	−2.74 (−9.49 to 4.00)	3.84 (−4.48 to 12.2)	−3.94 (−9.72 to 1.84)
Time	−0.27 (−1.19 to 0.65)	−1.18 (−1.84 to −0.52)*	−1.35 (−1.98 to −0.73)*

Footnote: YSP = Youth Smoking Prevalence. Baseline in calendar year 2012. Countries with low smoking prevalence: Belgium, Cyprus, Denmark, Estonia, Luxembourg, Poland, Slovakia, Sweden, and Netherlands; Countries with moderate smoking prevalence: Czechia, France, Germany, Hungary, Italy, Malta, Portugal, and Romania; Countries with high smoking prevalence: Austria, Bulgaria, Finland, Greece, Ireland, Latvia, Lithuania, Slovenia, and Spain. Data are presented as β (95% CI). β coefficients represent the percentage point change in youth smoking prevalence associated with a one-unit increase in the predictor or, in the case of a binary variable such as the age-of-sale law, the change associated with its implementation. Price of cigarettes is expressed as the real (inflation-adjusted) price per 20-cigarette pack (in euros); coefficients correspond to the change in prevalence associated with a €1 increase in the price per pack. *: $p < 0.05$.

Table 2: **Linear mixed-effects regression analysis of youth smoking prevalence in relation to price of cigarettes, the Tobacco Control Scale, age-of-sale law for tobacco purchase and time (year) in three country categories based on baseline youth smoking prevalence in 2012 (Low, Moderate, and High): overall and sex-stratified, EU26.**

smoking prevalence among males, whereas no significant associations were observed among females or at the EU level. These patterns were consistent across all baseline prevalence levels among males, but regional variation was observed, with price increases associated with substantial reductions in youth smoking across all subgroups (overall, males and females) in Southern Europe and among males in Northern Europe, while no

	Northern Europe	Western Europe	Southern Europe	Eastern Europe
All	N = 35	N = 30	N = 35	N = 30
Price of cigarettes	−1.58 (−4.18 to 1.03)	−0.45 (−3.28 to 2.38)	−7.13 (−10.93 to −3.32)*	−3.12 (−11.6 to 5.39)
Tobacco control scale	0.43 (−0.62 to 1.48)	−0.11 (−0.50 to 0.28)	0.02 (−0.29 to 0.32)	0.32 (−0.31 to 0.95)
Age-of-sale law	−6.96 (−20.7 to 6.79)	2.19 (−4.10 to 8.48)	3.87 (−1.58 to 9.32)	−10.5 (−21.35 to 0.32)
Time	−1.10 (−2.05 to −0.14)*	−0.55 (−1.35 to 0.26)	−0.62 (−1.21 to −0.04)*	−0.34 (−1.33 to 0.65)
Males	N = 35	N = 30	N = 35	N = 30
Price of cigarettes	−3.58 (−6.77 to −0.39)*	−3.73 (−7.49 to 0.02)	−6.56 (−11.80 to −1.32)*	−8.14 (−18.69 to 2.40)
Tobacco control scale	0.67 (−0.62 to 1.96)	−0.08 (−0.60 to 0.44)	−0.28 (−0.70 to 0.14)	0.21 (−0.57 to 0.99)
Age-of-sale law	−8.38 (−25.20 to 8.45)	8.35 (−1.60 to 16.70)	1.04 (−6.47 to 8.55)	−5.82 (−19.25 to 7.62)
Time	−1.05 (−2.22 to 0.12)	−0.41 (−1.48 to 0.66)	−0.36 (−1.17 to 0.45)	0.47 (−0.76 to 1.69)
Females	N = 35	N = 30	N = 35	N = 30
Price of cigarettes	0.79 (−1.80 to 3.38)	2.97 (−0.29 to 6.24)	−7.63 (−12.34 to −2.93)*	2.40 (−7.03 to 11.83)
Tobacco control scale	0.07 (−0.97 to 1.12)	−0.17 (−0.61 to 0.29)	0.32 (−0.05 to 0.70)	0.43 (−0.27 to 1.13)
Age-of-sale law	−4.84 (−18.52 to 8.83)	−4.18 (−11.44 to 3.08)	6.67 (−0.07 to 13.4)	−15.52 (−27.53 to −3.50)*
Time	−1.11 (−2.06 to −0.16)*	−0.73 (−1.66 to 0.20)	−0.91 (−1.63 to −0.18)*	−1.20 (−2.30 to −0.11)*

Footnote: Countries were classified into four regions for comparison: Northern Europe (Denmark, Ireland, Finland, Sweden, Estonia, Latvia, Lithuania), Western Europe (Austria, Belgium, France, Germany, Luxembourg, The Netherlands), Southern Europe (Greece, Spain, Italy, Portugal, Malta, Cyprus, Slovenia) and Eastern Europe (Bulgaria, Czechia, Hungary, Poland, Romania, Slovakia). Data are presented as β (95% CI). β coefficients represent the percentage point change in youth smoking prevalence associated with a one-unit increase in the predictor or, in the case of a binary variable such as the age-of-sale law, the change associated with its implementation. Price of cigarettes is expressed as the real (inflation-adjusted) price per 20-cigarette pack (in euros); coefficients correspond to the change in prevalence associated with a €1 increase in the price per pack. *: $p < 0.05$.

Table 3: **Linear mixed-effects regression analysis of youth smoking prevalence in relation to price of cigarettes, the Tobacco Control Scale, age-of-sale law for tobacco purchase and time (year) by subregions (Northern, Western, Southern, and Eastern Europe): overall and sex-stratified, EU26.**

such associations were found in Western or Eastern Europe. Age-of-sale laws were not significantly associated with changes in youth smoking prevalence at the EU level.

These declines align with the 2024 European School Survey Project on Alcohol and Other Drugs (ESPAD), which reported that cigarette use among 15–16-year-olds dropped from 27% in 2012 to 18% in 2024.[30] Nevertheless, the EU youth smoking prevalence (24.3% for males and 19.6% for females aged 15–24) remained higher than global estimates (20.1% for males, 5.0% for females) and higher than levels observed in other high-income regions at a similar stage of the tobacco epidemic.[5,28] For example, 18.4% for males and 13.3% for females in the United States, 17.1% and 15.0% in Canada, and 15.7% and 14.5% in Australia.[5] Substantial cross-country variation also persisted, with rising prevalence in several Eastern European countries, most of which are at stage 3 of the tobacco epidemic[27] which is characterised by stable adult smoking prevalence and steeply rising smoking-attributable mortality, raising particular concern.[28] Taken together, these results suggest that the EU remains far from achieving the tobacco endgame, highlighting the urgent need for stronger youth-focused tobacco control measures.

Furthermore, the observed trend may also partly reflect the increasing use of new tobacco and nicotine products, which were not captured in our study.[30] These products appeal strongly to youth and are associated with increased risks of initiation and dual or poly-use.[31–33] Such patterns may explain why, despite declines in some countries with strong tobacco control policies, youth smoking has remained stable or even increased in other countries with weaker regulation, resulting in persistently high overall prevalence in the EU.[30] However, evidence on their overall impact remains mixed; some studies have indicated that e-cigarette use increases the likelihood of subsequent smoking, while others, including recent findings from an Irish population study,[34] have suggested limited displacement or continuation of smoking regardless of prior e-cigarette use. These uncertainties call for monitoring the uptake of new products alongside conventional smoking when evaluating youth-focused tobacco control policies.

Our correlation analyses showed that countries with greater price increases experienced larger reductions in youth smoking, consistent with existing evidence that young people are particularly price-sensitive due to lower consumption and limited disposable income.[10–12,15,27,35] In contrast, this association was not significant at the EU level in our panel-data analyses, which aligns with previous European research findings.[36] This discrepancy may reflect (1) heterogeneity in tobacco control policy implementation and epidemic stage across countries, (2) stagnant price in most countries except for Finland, France, and Ireland, and (3) substitution with alternative products, cross-border purchases, and illicit trade, which may offset the effects of taxation by sustaining affordability.[28,37,38] First, the TCS report revealed these disparities, with scores ranging from 43 in Germany to 82 in Ireland, and 12 countries scored below 50, indicating generally weak implementation levels.[37] Moreover, although cigarette prices are primarily raised through taxation, the tobacco industry can absorb part of these costs to keep prices affordable, limiting the impact of on youth smoking.[1,39] Substitution with cheaper alternatives such as roll-your-own (RYO) tobacco provides another mechanism.[25] Prior research has noted that despite rising inflation-adjusted cigarette prices, substantial price gaps between manufactured cigarettes and RYO tobacco have persisted across the EU, with prevalence of RYO use ranging from 42% of smokers in Belgium to 3% in Romania.[39] In countries where RYO tobacco is widespread and prices are stagnant, substitution could mitigate the impact of price increases.

Our findings support that the impact of cigarette price may differ by sex, aligning with existing evidence that females are generally less responsive to price changes than males.[10,12,17] Nonetheless, females are more likely than males to be occasional or light smokers, a group typically considered more price-sensitive; one possible explanation is differences in sources of cigarette access.[1,2,5] Previous studies have suggested that adolescent boys are more likely to purchase cigarettes directly from shops or vending machines and are therefore more directly affected by changes in price policy. In contrast, girls are more likely to obtain cigarettes through non-commercial channels, such as family members or older peers, thereby weakening the impact of cigarette prices even though their smoking patterns suggest greater price sensitivity.[12,30,40,41] Notably, female smoking still declined with each successive year despite no significant association with cigarette prices, indicating that broader contextual factors may have contributed (e.g., changing social norms or growing availability of new tobacco- and nicotine-containing products). The findings emphasise the need for sex-specific interventions to achieve greater reductions in youth smoking.

Our results also indicate regional variations in the impact of cigarette prices. In Southern Europe, price increases were negatively associated with youth smoking across both sexes, consistent with evidence that taxation is particularly effective in populations experiencing economic constraints.[10–12,27] In Northern Europe, the impact of cigarette price was observed only among males. Some countries in the region (e.g., Finland, Ireland) have sustained high taxation, along with other robust tobacco control measures,[37] whereas others (e.g., Estonia, Latvia) have had lower prices and little change in female smoking since 2012, which may have diluted

the overall impact. In contrast, in Eastern and Western Europe, no such associations were found, which may reflect complex interactions between social factors, weak enforcement of other tobacco control measures (e.g., advertising bans, health education), and the expansion of informal markets (e.g., illicit trade).[27,37,38,42] In these regions, where price increases have been modest and enforcement relatively weak, the impact of price on smoking behaviour may have been attenuated, suggesting that youth who smoke may be more addicted or embedded in smoking cultures that reduce responsiveness to price changes.[12]

Notably, the introduction of 18+ age-of-sale laws was significantly associated with a reduction in youth smoking among females in Eastern Europe, but no significant associations were observed in other regions or at the EU level. This finding is consistent with previous research suggesting that restrictions on sales to minors are often poorly enforced.[30] For example, one study reported that during the 2010s, initiation rates of smoking among minors exceeded those of young adults, indicating that many began smoking regularly before reaching the legal purchasing age.[29] Similarly, the 2024 ESPAD survey found that 55% of students perceived cigarettes as easily accessible.[30] Several mechanisms might explain this. First, regional differences in the timing of implementing age-of-sale laws may play a role. In many Northern Europe countries (e.g., Sweden, Ireland, Finland) and some in Western Europe countries (e.g., France, Germany), the age-of-sale laws were implemented before the study period, and any policy effects may have already materialised. Moreover, smoking uptake patterns vary by region, for instance, in Eastern Europe, initiation often occurs later, typically during early adulthood after individuals have already reached the legal purchasing age.[43] In such contexts, age-of-sale laws may coincide more directly with the usual age of initiation, thereby enhancing their potential impact. In contrast, in Western Europe (e.g., the Netherlands, France, and Belgium), where earlier initiation is more common, and smoking among minors may be more strongly influenced by social factors such as family and peer behaviours, this potentially limited the immediate effectiveness of legal age restrictions.[43,44] Although all EU countries have set 18 years as the minimum legal purchase age, many have not prohibited vending machines, internet sales, or alternative tobacco products.[30] Consequently, widespread access through these channels may have weakened the overall impact of age-of-sale laws.[17,45] Previous studies have indicated vending machines as a particularly accessible source of tobacco for European youth, and comprehensive bans could reduce youth smoking substantially.[41,46]

Our study indicates that the impact of current cigarette prices and age-of-sale laws varies by sex and region and may depend on enforcement levels and broader policy and cultural contexts. As strongly recommended by the WHO FCTC, comprehensive and well-enforced tobacco control policies are needed, including stricter age-of-sale laws enforcement, enhanced retailer compliance, and bans on vending machines and other access channels.[1,12,15] The lack of standardised indicators for enforcement levels remains a major challenge, while the rapid growth of new nicotine-containing products risks undermining existing progress if regulation lags. To safeguard public health, the European Commission should urgently revise the Tobacco Products Directive and the Tobacco Tax Directive, strengthening taxation, harmonising affordability across products and countries, and extending regulation to all nicotine-containing products.[10,11,13]

This study is the first to systematically examine the impact of cigarette prices and 18+ age-of-sale laws on changes in youth smoking across the EU, introducing a longitudinal perspective through the integration of data from five cross-sectional surveys conducted using consistent methodology across countries and over time. We also conducted a sensitivity analysis to account for the wide range of estimates. However, some limitations should be considered. Smoking status was self-reported in all surveys, which introduces the possibility of response bias. In countries where smoking is socially less acceptable, particularly among certain demographic groups, smoking may be under-reported. However, self-reports of smoking status have acceptable validity.[47] Although the sample size was adequate for EU- and regional-level estimates, for countries with low smoking prevalence, estimates are based on a smaller number of respondents, which could lead to greater variance or outliers. The use of data from multiple EU countries enabled us to capture temporal trends at the EU level; however, the ecological nature of the analysis relied on a relatively small number of country-level observations. As a result, findings reflect associations at the population level and cannot be interpreted as individual-level causal relationships. Nonetheless, given our focus on national trends and policy impacts, the ecological approach was appropriate, and the risk of ecological fallacy is limited. While variations in policy implementation timing and overlapping secular trends may limit our ability to isolate the effects of specific measures such as 18+ age-of-sale laws, the TCS remains the best available proxy for comparing national tobacco control policy implementation across the EU. Although it does not capture enforcement (except for smoke-free laws) and was not significantly associated with youth smoking in our analyses, it still provides valuable comparative insight into policy environments across countries. A further limitation is that the enforcement level could not be included in the model, as no EU-wide comparable indicator is available. Lastly, this study focused exclusively on smoked tobacco and did not include smokeless tobacco, e-cigarettes,

nicotine pouches, or heated tobacco products. Previous studies have shown that these new tobacco and nicotine-containing products comprise an increasingly important share of tobacco use among young people.[30,31,33]

Despite progress in reducing youth smoking in the EU, nearly a quarter (22.2%) of individuals aged 15–24 years, or around 10 million young people, continued to smoke in 2023. Current taxation and age-of-sale policies appear insufficient to further accelerate decline towards the tobacco endgame target. Strengthening the enforcement of current policies and expanding the implementation of comprehensive tobacco control measures, while addressing disparities across sexes and regions, will be important to achieve substantial reductions in youth smoking. This study should not be misinterpreted as evidence that taxation and age-of-sale policies are ineffective; rather, their potential impact has likely been constrained by insufficient enforcement across the EU.

Contributors

Conceptualisation: AF. Methodology and study design: AT, AF. Collected data and prepared database for analysis: AT. Contributed to the strategy of analysis: AT, AF, SG and EF. Analysed data: AT. Interpreted data results: all authors. Drafted manuscript AT. Critically revised manuscript: all authors. Approved final manuscript version: all authors. Guarantors: AF, CM and EF.

Data sharing statement

The datasets used in the current study are publicly available. Information on how to access the data can be found at GESIS Data Archive (https://www.gesis.org/en/home).

Declaration of interests

The authors have no interest to declare.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanepe.2025.101511.

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