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Association of national smoke-free policies with per-capita cigarette consumption and acute myocardial infarction mortality in Europe

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ABSTRACT

Background Evidence on the association between smoke-free policies and per-capita cigarette consumption and mortality due to acute myocardial infarction (AMI) in Europe is limited. Hence, we aimed to assess this association and to evaluate which factors influence it.

Methods We performed an interrupted time series analysis, including 27 member states of the European Union and the UK, on per-capita cigarette consumption and AMI mortality.

A multivariate meta-regression was used to assess the potential influence of other factors on the observed associations.

Results Around half of the smoke-free policies introduced were associated with a level or slope change, or both, of per-capita cigarette consumption and AMI mortality (17 of 35). As for cigarette consumption, the strongest level reduction was observed for the smoking ban issued in 2010 in Poland (rate ratio (RR): 0.47; 95% CI: 0.41, 0.53). Instead, the largest level reduction of AMI mortality was observed for the intervention introduced in 2012 in Bulgaria (RR: 0.38; 95% CI: 0.34, 0.42).

Policies issued more recently or by countries with a lower human development index were found to be associated with a larger decrease in per-capita cigarette consumption. In addition, smoking bans applying to bars had a stronger inverse association with both cigarette consumption and AMI mortality.

Conclusions The results of our study suggest that smoke-free policies are effective at reducing per-capita cigarette consumption and AMI mortality. It is extremely important to monitor and register data on tobacco, its prevalence and consumption to be able to tackle its health effects with concerted efforts.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous studies do not consistently support an inverse association between national smoke-free policies and per-capita cigarette consumption, and evidence on their association with mortality due to acute myocardial infarction in Europe is limited.

WHAT THIS STUDY ADDS

⇒ The findings of this study suggest that national smoke-free policies in Europe were associated with reductions in both per-capita cigarette consumption and mortality due to acute myocardial infarction.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Smoke-free policies have beneficial effects on populations' health, especially in countries with lower socioeconomic indicators, and should thus be adopted or tightened, according to the local context.

INTRODUCTION

Europe is facing a high prevalence of tobacco smokers, even if trends are in decline.[1] Smoking is a well-known risk factor for cardiovascular, respiratory diseases and cancer, and their related mortality.[2] In particular, previous studies have shown that acute myocardial infarction (AMI) can result in very high mortality at 30 days[3] and its occurrence reduces if exposure to cigarette smoking or secondhand smoking lowers.[4 5] Tobacco use can be quantified using various data sources, but cigarette consumption can be considered the most accurate and most comparable indicator as it can be derived from administrative sales data.[6]

To address this epidemic, several regulations, laws and provisions were implemented at international (such as the international WHO Framework Convention on Tobacco Control) and national laws and, in Europe, the 2014 Tobacco Product Directive.

Several studies reported single-country or few-country experiences regarding the effects of smoke-free policies on cigarette consumption or mortality due to AMI.[7] No previous study, however, evaluated the impact of national smoke-free policies with a comprehensive approach including all European countries. Thus, the aim of our study was to evaluate the impact of these policies on per-capita cigarette consumption and AMI mortality in the member states of the European Union (EU) and the UK and to assess which factors influence their association.

METHODS

Summary of national smoking bans

A search for any smoking ban policies introduced across EU countries and the UK, issued in the period of data availability, was performed on official national gazettes and government websites, as well as additional sources (European Commission,[8]

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European Public Health Alliance,[9] European Network for Smoking and Tobacco Prevention,[10] Smoke-Free Partnership[11]). Years of entry into the force of smoke-free policies are reported in online supplemental table S1.

Data sources

A previous systematic collection of national cigarette consumption in 1970–2015 was used as a data source for per-capita cigarette consumption for 22 countries of interest until 2015.[6]

Data regarding AMI mortality (ICD-10 codes I21-I22) were retrieved from the Eurostat database,[12] with data available for 26 countries in 1994–2017.

The study was based on publicly available summary data, hence no ethics approval was requested.

Statistical analysis

We performed an interrupted time series analysis to evaluate the effect of smoke-free policies on per-capita cigarette consumption and AMI mortality, by comparing the period following the entry into force of the law (online supplemental table S1) with the pre-intervention period. For the analysis of cigarette consumption, we used negative binomial regression with the outcome being national cigarette consumption (in millions) and a log offset by the national population. We included in the model a binary ban term to determine the level or step-change for each smoking ban law, together with a linear time variable (in years) to account for the pre-existing long-term trend and pattern of cigarette consumption, and an interaction term between time (centred on the intervention) and the binary ban term, representing the slope change following the intervention.[13] Additionally, we assessed the occurrence of autocorrelation by visual inspection of partial autocorrelation function plots and added to the model the appropriate order of lagged residuals, where needed. SEs were scaled to account for overdispersion.[13]

We followed a similar approach for the analysis of AMI mortality, but in this case, the outcome of the model was represented by the observed number of deaths due to AMI and the log offset by the number of expected deaths due to AMI, computed using data from the Eurostat database. Additionally, in order to assess whether the effect of smoke-free policies on this indicator could occur with a lag, we repeated the analysis on AMI mortality by shifting the interventions to 2 years later.[13] The rationale for using this 2-year criterium derives from previous observations reporting that the reduction of AMI mortality rates was stronger in the second year following the introduction of a smoke-free policy.[14]

In order to improve the statistical power of the analysis and to be able to assess slope changes following interventions, we included in the analyses only interventions with data availability for at least 3 years before and after the entry into force of the law.[15] Whenever the exclusion of smoke-free policies was requested for this reason, we omitted the corresponding periods preceding or following the smoking ban, as needed, to limit the effect on our results of laws not included in the analysis.

For countries with more than one law separated by less than 3 years, we included in the main analysis only the first one entering into force. However, for countries with more than two laws, with fewer than 3 years between each of them but with at least 3 years between the first and the last one, we used the years of entry into force of the first and the last law as intervention points in the analysis (online supplemental table S1). In both cases, we assume that the effect of further smoke-free policies closely following or modifying the first one (with an interval between the two lower than 3 years), which is the law included in the analysis, can be considered additive with that of the first law itself (ie, the findings reported in the results section for a smoking ban law L_t issued at the time t and followed by a second law L_{t+1} that entered into force at the time $t+1$ actually represent the overall effect of both laws, considered together). We also carried out a secondary analysis on both per-capita cigarette consumption and AMI mortality by including all smoke-free policies in the time periods with available data, even if data for at least 3 years before and after their entry into force were not available. In this case, bans issued over consecutive years have only one related data point corresponding to the year of their entry into force, thus preventing the assessment of slope changes. For this reason, in this secondary analysis, we assessed only level changes, using the same approach described above. At least one data point before and after the law was anyway requested to allow computation.

Lastly, we carried out a multivariate meta-regression analysis with a restricted maximum likelihood approach to investigate whether the year of entry into force of the law, human development index (HDI), the proportion of the population older than 65 years and places to which smoking bans apply and their strength influence the level and the slope change associated with smoke-free policies from the time series analysis on per-capita cigarette consumption and AMI mortality. HDI is a composite indicator estimating the level of development of a county and is based on life expectancy, education and gross national income per capita. Data regarding the HDI (at the year of entry into force of the law) were retrieved from the United Nations Development Programme,[16] while information on the age structure of the population (year of entry into force) was obtained from the World Bank Dataset.[17] Details on the places where smoking ban laws apply were identified from websites and documents (eg, laws themselves) retrieved from the search carried out to identify smoking bans, as described above, and are reported in online supplemental table S2. We used estimates of association related to both level and slope changes from the main analysis as dependent variables in the meta-regression model. Instead, we excluded from the analysis countries with more than one law separated by less than 3 years between them, since in this case results from the time series analysis actually summarise the effect of more than one intervention, as stated above.

All statistical analyses were conducted using STATA software V.17 (StataCorp LLC).

RESULTS

Per-capita cigarette consumption

Data showed decreasing trends of per-capita consumption over recent decades for all countries included in the analysis (online supplemental figure S1). Results of the main analysis are reported in table 1, showing a level change for 8 interventions from 6 countries and a slope change for 15 interventions from 11 countries. Interventions in Belgium (2011) and Germany (2007) were associated with a level reduction only, while those in the Czech Republic (2006), France (1991, 2007), Greece (2009), Ireland (2004), Romania (2008), Slovenia (2007), Spain (2006) and UK (2007) were associated with a decreased slope. Instead, significant reductions in both the level and the slope of per-capita cigarette consumption were observed for six smoking bans, specifically in Hungary (1999, 2012), Poland (1995, 2010), Portugal (2008) and Spain (2011). Additionally, near-significant inverse associations between smoke-free policies and cigarette

Table 1 Results of the interrupted time series analysis regarding cigarette consumption of 22 countries included in the study (results representing significant reductions are reported in bold)

Country, year of the intervention	Level change RR (95% CI)	Slope change RR (95% CI)
Austria		
2009	0.98 (0.92, 1.04)	0.98 (0.97, 1.00)
Belgium		
2006	1.03 (0.90, 1.17)	0.98 (0.94, 1.03)
2011	**0.84 (0.72, 0.99)**	1.04 (0.98, 1.12)
Croatia		
2008	0.95 (0.79, 1.15)	0.98 (0.95, 1.02)
Czech Republic		
2006	0.99 (0.88, 1.11)	**0.95 (0.94, 0.97)**
Denmark		
2007	1.15 (1.01, 1.30)	0.97 (0.92, 1.02)
2012	0.97 (0.84, 1.13)	0.91 (0.82, 1.01)
Estonia		
2005	1.09 (0.74, 1.59)	0.94 (0.87, 1.00)
France		
1976	0.98 (0.84, 1.13)	0.97 (0.93, 1.02)
1991	0.71 (0.31, 1.63)	**0.93 (0.89, 0.98)**
2007	0.23 (0.05, 1.13)	**0.94 (0.90, 0.99)**
Germany		
2007	**0.75 (0.66, 0.84)**	1.00 (0.98, 1.02)
Greece		
2003	1.07 (0.92, 1.24)	0.98 (0.93, 1.02)
2009	0.90 (0.77, 1.05)	**0.87 (0.84, 0.91)**
Hungary		
1999	**0.82 (0.72, 0.92)**	**0.96 (0.95, 0.98)**
2012	**0.48 (0.39, 0.60)**	**0.73 (0.64, 0.84)**
Ireland		
1988	1.01 (0.93, 1.09)	1.02 (1.01, 1.03)
2004	1.25 (1.06, 1.47)	**0.95 (0.94, 0.96)**
Italy		
1975	1.10 (0.97, 1.26)	0.99 (0.94, 1.05)
2005	0.90 (0.17, 4.69)	0.97 (0.92, 1.02)
Lithuania		
2007	1.18 (0.76, 1.85)	1.00 (0.94, 1.07)
Netherlands		
1990	1.03 (0.88, 1.19)	1.02 (1.01, 1.04)
2004	1.25 (0.93, 1.67)	1.04 (0.94, 1.14)
2008	1.48 (1.09, 2.01)	0.95 (0.90, 1.01)
Poland		
1995	**0.90 (0.84, 0.97)**	**0.96 (0.95, 0.97)**
2010	**0.47 (0.41, 0.53)**	**0.93 (0.90, 0.96)**
Portugal		
2008	**0.75 (0.65, 0.86)**	**0.94 (0.91, 0.98)**
Romania		
2008	0.86 (0.71, 1.05)	**0.94 (0.89, 0.98)**
Slovakia		
2004	0.85 (0.71, 1.03)	1.11 (1.05, 1.18)
2009	1.24 (0.98, 1.57)	1.04 (1.00, 1.08)
Slovenia		
2007	1.06 (0.93, 1.21)	**0.96 (0.93, 0.98)**
Spain		
2006	0.97 (0.88, 1.07)	**0.94 (0.90, 0.97)**
2011	**0.59 (0.53, 0.65)**	**0.91 (0.87, 0.96)**
Sweden		
2005	0.95 (0.80, 1.11)	1.00 (0.97, 1.02)
UK		
2007	0.89 (0.76, 1.05)	**0.96 (0.93, 0.99)**

RR, rate ratio.

consumption slope were detected for Austria (2009) and Estonia (2005).

In the secondary analysis of policies with available data for less than 3 years before and after their introduction (online supplemental table S3), four interventions were associated with a level reduction of per-capita cigarette consumption, in Croatia (2009), Germany (2007, 2008) and Greece (2010). Instead, the effect of the intervention in Belgium (2011) became in-significant.

AMI mortality

As for AMI mortality, similar decreasing trends were observed for countries included in the analysis (online supplemental figure 2), but the effect of smoke-free policies was more evenly distributed between level and slope changes than for cigarette consumption (table 2). Indeed, 13 and 11 interventions from 9 and 10 countries were associated with reduced levels and slope of AMI mortality, respectively. In detail, interventions in Belgium (2006, 2011), Cyprus (2010), Portugal (2008) and UK (2007) were inversely associated just with the level change of AMI mortality, while those in Estonia (2005), Finland (2007), Latvia (2005), Malta (2011) and Sweden (2005) led to reductions of the slope only. A similar number of interventions were associated with both reduced level and slope of AMI mortality, specifically those in Bulgaria (2005, 2012), Denmark (2012), Italy (2005), Romania (2008) and Spain (2006, 2011). Additionally, smoke-free policies in Greece (2003, 2009) and Luxembourg (2006) were near-significantly associated with slope reductions of AMI mortality.

When shifting the intervention to 2 years later, most results became non-significant (table 2). However, interventions in France (2007), Greece (2009), Malta (2004), Slovakia (2004) and Slovenia (2007) additionally showed significant associations with a level reduction of AMI mortality, while those in Greece (2003) and Luxembourg (2006) resulted to be inversely associated with its slope.

When considering smoke-free policies with data availability for less than 3 years before and after their entry into force (online supplemental table S4), all those issued in Belgium (2006, 2007, 2008, 2010, 2011) and Romania (2008, 2016) over the years, together with the one introduced in France in 2008, were found to be associated with level reductions of AMI mortality.

Meta-regression analysis

The results of the meta-regression analysis regarding the factors influencing the association between smoke-free policies and per-capita cigarette consumption are reported in table 3. Interventions issued more recently or by countries with a lower HDI were found to be associated with larger reductions in per-capita cigarette consumption. Additionally, bans applying to bars showed a stronger association with reduction in per-capita consumption.

Total smoking bans in bars were found to be more strongly associated with level reduction of AMI mortality. Instead, total

Table 2 Results of the interrupted time series analysis regarding AMI mortality of 26 countries included in the study (results representing significant reductions are reported in bold)

Country, year of the intervention	Actual year of intervention		Intervention shifted to 2 years later	
	Level change	Slope change	Level change	Slope change
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
Austria				
2009	1.01 (0.95, 1.07)	1.03 (1.02, 1.04)	0.91 (0.82, 1.01)	1.03 (1.02, 1.05)
Belgium				
2006	**0.94 (0.90, 0.97**)	1.01 (0.99, 1.03)	0.96 (0.89, 1.04)	1.02 (1.00, 1.04)
2011	**0.98 (0.95, 0.999**)	0.99 (0.99, 1.00)	0.98 (0.91, 1.05)	1.00 (0.99, 1.02)
Bulgaria				
2005	**0.62 (0.58, 0.66**)	**0.93 (0.91, 0.94**)	0.99 (0.70, 1.39)	0.96 (0.91, 1.00)
2012	**0.38 (0.34, 0.42**)	**0.97 (0.95, 0.98**)	0.68 (0.38, 1.24)	1.00 (0.90, 1.11)
Croatia				
2008	0.96 (0.91, 1.02)	1.02 (1.01, 1.03)	0.96 (0.91, 1.02)	1.02 (1.01, 1.03)
Cyprus				
2010	**0.83 (0.71, 0.97**)	0.98 (0.95, 1.01)	0.97 (0.78, 1.21)	1.01 (0.97, 1.05)
Czech Republic				
2006	0.95 (0.85, 1.07)	1.00 (0.98, 1.02)	1.07 (0.92, 1.23)	1.00 (0.98, 1.02)
Denmark				
2007	0.96 (0.84, 1.11)	0.97 (0.92, 1.02)	1.11 (0.81, 1.53)	0.96 (0.92, 1.01)
2012	**0.83 (0.70, 0.99**)	**0.96 (0.93, 0.997**)	0.82 (0.43, 1.54)	0.99 (0.89, 1.09)
Estonia				
2005	1.00 (0.83, 1.20)	**0.97 (0.94, 0.998**)	0.96 (0.77, 1.19)	0.97 (0.95, 1.00)
Finland				
2007	0.96 (0.91, 1.01)	**0.98 (0.97, 0.99**)	1.05 (0.98, 1.13)	**0.98 (0.97, 0.99**)
France				
2007	0.96 (0.90, 1.02)	1.01 (0.99, 1.02)	**0.91 (0.87, 0.95**)	1.01 (1.00, 1.02)
Greece				
2003	1.04 (0.95, 1.14)	0.98 (0.95, 1.00)	1.03 (0.90, 1.19)	**0.98 (0.95, 0.998**)
2009	0.88 (0.76, 1.01)	0.98 (0.97, 1.00)	**0.85 (0.74, 0.97**)	0.98 (0.96, 1.00)
Hungary				
1999	1.03 (0.92, 1.14)	1.01 (0.98, 1.05)	0.98 (0.92, 1.05)	1.01 (0.99, 1.03)
2012	1.24 (0.72, 2.13)	1.02 (0.98, 1.06)	0.98 (0.73, 1.30)	1.04 (1.00, 1.08)
Ireland				
2004	1.03 (0.96, 1.11)	1.02 (1.00, 1.04)	0.99 (0.94, 1.05)	1.02 (1.00, 1.03)
Italy				
2005	**0.72 (0.55, 0.95**)	**0.96 (0.93, 0.996**)	1.09 (0.95, 1.25)	0.98 (0.94, 1.02)
Latvia				
2005	1.18 (1.02, 1.36)	**0.95 (0.93, 0.98**)	1.54 (1.42, 1.68)	**0.94 (0.93, 0.95**)
Lithuania				
2007	0.96 (0.84, 1.10)	0.98 (0.96, 1.01)	1.00 (0.88, 1.14)	0.98 (0.96, 1.00)
Luxembourg				
2006	1.17 (0.93, 1.49)	0.96 (0.91, 1.00)	1.24 (0.85, 1.81)	**0.95 (0.90, 0.996**)
2014	0.77 (0.52, 1.13)	0.99 (0.88, 1.13)	1.63 (0.62, 4.30)	0.83 (0.64, 1.06)
Malta				
2004	1.01 (0.90, 1.13)	0.99 (0.97, 1.02)	**0.80 (0.66, 0.98**)	1.04 (1.01, 1.07)
2011	1.26 (1.03, 1.54)	**0.95 (0.92, 0.97**)	1.22 (0.90, 1.66)	0.97 (0.92, 1.01)
Poland				
2010	0.93 (0.85, 1.01)	1.00 (0.97, 1.02)	0.94 (0.86, 1.03)	1.02 (1.00, 1.03)
Portugal				
2008	**0.89 (0.83, 0.94**)	1.00 (0.99, 1.01)	0.93 (0.83, 1.05)	1.00 (0.98, 1.02)
Romania				
2008	**0.84 (0.78, 0.91**)	**0.97 (0.96, 0.99**)	0.96 (0.84, 1.10)	0.99 (0.97, 1.01)
Slovakia				
2004	1.03 (0.68, 1.58)	1.36 (1.21, 1.53)	**0.44 (0.23, 0.88**)	1.33 (1.18, 1.49)
2009	3.67 (1.88, 7.18)	1.11 (1.03, 1.20)	1.44 (0.87, 2.40)	1.15 (1.07, 1.24)
Slovenia				

Continued

Table 2 Continued

Country, year of the intervention	Actual year of intervention		Intervention shifted to 2 years later	
	Level change	Slope change	Level change	Slope change
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
2007	0.95 (0.83, 1.07)	1.07 (1.05, 1.09)	**0.79 (0.66, 0.93)**	1.07 (1.05, 1.10)
Spain				
2006	**0.94 (0.90, 0.97)**	**0.96 (0.95, 0.97)**	0.99 (0.89, 1.10)	**0.97 (0.96, 0.99)**
2011	**0.77 (0.74, 0.81)**	**0.98 (0.97, 0.99)**	**0.81 (0.72, 0.90)**	0.99 (0.97, 1.01)
Sweden				
2005	1.02 (0.98, 1.06)	**0.97 (0.96, 0.98)**	1.11 (1.06, 1.15)	**0.97 (0.97, 0.98)**
UK				
2007	**0.93 (0.89, 0.98)**	1.02 (1.01, 1.03)	**0.84 (0.80, 0.89)**	1.03 (1.02, 1.04)

RR, rate ratio.

smoking bans in public transport appeared to have the opposite effect.

DISCUSSION

To our knowledge, this is the first study comprehensively assessing the impact of smoke-free policies on per-capita cigarette consumption and AMI mortality across EU member states and the UK. Overall, the results of our study showed that around half of smoke-free policies (17 out of 35) included in the main analysis led to a reduced level, slope or both, of per-capita cigarette consumption, and findings were similar for AMI mortality (17 out of 35). For AMI mortality, most results became non-significant when shifting the intervention to 2 years later, although some interventions (n=7) were additionally found to be associated with reduced mortality, suggesting that the effect of smoke-free policies on AMI mortality, at least for some countries, required some time to occur. The secondary analysis including all policies issued provided more detailed findings, however, these results are likely underpowered since there was a single data point for many interventions included in the analysis. In this context, monthly or weekly data on cigarette consumption and AMI mortality could be better suited to investigate

Table 3 Results of the meta-regression analysis to assess which factors influence the association between smoke-free policies and per-capita cigarette consumption (significant results are reported in bold)

Factors	Cigarette consumption		AMI mortality	
	Level change	Slope change	Level change	Slope change
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
Year of intervention	**0.91 (0.87, 0.95)**	**0.99 (0.98, 0.997)**	0.97 (0.93, 1.01)	1.00 (0.99, 1.01)
Proportion of population aged >65 years	1.02 (0.96, 1.09)	1.01 (0.99, 1.02)	0.98 (0.91, 1.05)	0.99 (0.98, 1.00)
HDI	**89.53 (2.48, 3238.05)**	1.53 (0.68, 3.45)	1.00 (0.05, 20.56)	1.16 (0.75, 1.80)
Places where ban applies, type of ban				
Workplace				
No or partial ban	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Near-total or total ban	1.48 (0.96, 2.27)	1.07 (0.98, 1.17)	1.24 (0.75, 2.04)	1.00 (0.93, 1.08)
Enclosed public places				
Non-total ban	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Total ban	1.07 (0.70, 1.64)	1.05 (0.95, 1.15)	1.09 (0.74, 1.58)	1.00 (0.94, 1.05)
Restaurants				
No or partial ban	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Near-total or total ban	1.08 (0.89, 1.32)	1.00 (0.96, 1.04)	1.14 (0.88, 1.47)	0.98 (0.94, 1.02)
Bars				
No ban	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Partial ban	**0.62 (0.41, 0.96)**	0.92 (0.85, 1.01)	0.61 (0.35, 1.06)	0.98 (0.90, 1.06)
Near-total ban	**0.44 (0.27, 0.71)**	**0.89 (0.81, 0.99)**	0.55 (0.28, 1.05)	1.00 (0.91, 1.09)
Total ban	**0.31 (0.15, 0.65)**	**0.83 (0.70, 0.98)**	**0.34 (0.16, 0.75)**	1.01 (0.90, 1.12)
Public transports				
Non-total ban	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
Total ban	1.45 (0.96, 2.18)	1.04 (0.95, 1.14)	**1.46 (1.03, 2.09)**	0.99 (0.94, 1.04)

Partial ban: smoking is allowed in smoking zones or ban exemptions for certain categories of venues. Near-total ban: smoking is allowed only in enclosed separate rooms. Total ban: smoking is not allowed. Countries with more than one law separated by less than 3 years between each other were excluded from the analysis. Interventions with missing values of variables included in the meta-regression models were excluded from the analysis (online supplemental table S2). Investigated factors were included as separate variables in the same meta-regression model, either as continuous (year of intervention, proportion of population aged >65 years, HDI) or categorical variables (places where the ban applies, with a separate variable for each considered place).
HDI, human development index; RR, rate ratio.

the effect of smoking bans with short time intervals. Lastly, we found that the association between smoke-free policies and the reduction of per-capita consumption could be affected by the year of entry into force and by socioeconomic conditions of the population. Also, the application of smoke-free policies to bars appeared to be associated with a higher effect related to both cigarette consumption and AMI mortality.

Our findings are not completely consistent with previous literature that showed that, in Europe, the introduction of such tobacco control policies does not always lead to a decrease of active smoking measures over time.[18–20] In particular, a review provided inconsistent evidence about the effectiveness of smoke-free policies from 10 of the countries included in our study.[19] For instance, while a few studies showed an association of the 2005 Italian smoking ban with a reduction of smoking prevalence,[21–23] a later one did not confirm these findings over a longer period of time,[24] with our results on cigarette consumption agreeing with this latter study. Previous reports for the effect of smoke-free policies in Belgium were in line with our results,[25] while others did not find an appreciable effect of smoke-free policies on smoking habits in the UK and in Ireland.[26–28] As for AMI mortality, previous studies showed consistent reductions following smoke-free policies, though the number of studies, especially European ones, is limited.[19] These mixed findings may be also due to the different indicators used (ie, prevalence or consumption).

A recent study reported that only a total ban was associated with a reduction of cigarette sales in Spain, partly in contrast with our findings.[29] Additionally, the 2004 smoking ban in Ireland was reported as effective at reducing smoking prevalence among young people.[30] Previous reports also showed an increased level of awareness of tobacco-related susceptibility diseases over time,[31 32] which could also be increased by other types of interventions such as pictorial health warnings.[31] Thus, the most recent smoke-free policies might be more effective at reducing cigarette consumption. This may depend on several factors that moderate the effect of the policy, for example, knowledge; awareness; risks, costs and benefits of smoking or quitting; concerns about exposing others to smoke; and information campaigns that can potentially be effective among some age groups. However, since tobacco has an additive nature, the impact of policies may take a long to fully appear as users respond to it.[33] A previous meta-analysis found that smoke-free policies were effective at reducing AMI mortality, particularly those applying in workplaces, restaurants and bars,[7] with our findings confirming this previous observation only for the latter. Our results on per-capita cigarette consumption did not completely parallel those on AMI mortality, suggesting that there could be other mediators. In this context, a primary role could be played by a reduction of the population's exposure to second-hand smoke,[19] both among smokers and non-smokers, which could thus explain the association of bans with AMI mortality.

The validity of findings from quasi-experimental studies, such as time series ones, can be limited because of bias due to several factors. Confounding can potentially be responsible for spurious associations or can mask real ones. In fact, our study did not take into account the effect of other interventions occurring in the period of interest, such as taxation,[34] nor did it include information on the use of several types of tobacco products other than cigarettes, and it only considered the number of cigarettes per capita, not the smoking prevalence. Taxation, in particular, is nowadays among the most effective measures at reducing tobacco use across different demographic and socioeconomic groups,[34] however, bans were highly influential in the 2000s,[35] also from a cultural and behavioural point of view.[36] The database we used for the analysis on per-capita cigarette consumption derived its data from governmental sources, therefore lacking data on illicit cigarette trade, a hardly estimable phenomenon, due to its clandestine nature, that undergoes variation over time in terms of magnitude. Furthermore, smoke-free policies strongly target certain groups, such as young adults, unmarried persons and city dwellers, who attend public places more often,[37] while other population groups might be less affected. Our study did not consider potentially different effects of smoke-free policies across different population groups, and how exposure to second-hand smoke could be directly affected by this type of intervention. Sustained and stronger efforts against smoking need to be put in place, with recent evidence confirming a relevant role of price increases and taxation[34] that could be effective means of tobacco control together with smoke-free policies.

While a time-series analysis could be reasonable for cigarette consumption since the effect of a smoking ban could be expected to occur right away after its introduction, the same analysis conducted on clinical outcomes could be less robust because most major smoking-related diseases have long time lags.[38] Since the Eurostat database provides data only on mortality and not on hospitalisations, which could in turn be a better indicator of the effectiveness of smoke-free policies,[13] we limited the analysis of clinical outcomes to AMI mortality, which has been reported to consistently reduce after the introduction of these policies even after a short period of time.[7 19] We also assessed whether the effect of smoke-free policies on this outcome could be lagged, finding limited, although not conclusive, evidence supporting this hypothesis. Further research should consider other forms of tobacco and monitor these indicators among disadvantaged groups of the population, who have shown increasing smoking prevalence.[39] Tackling tobacco with appropriate legislation, programmes and research to identify the best ways to decrease smoking consumption in the population is still extremely relevant.

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