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Getting “The whole picture”: A review of international research on the outcomes of regulated cannabis supply

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ABSTRACT

Background: Several jurisdictions have pursued reforms that regulate cannabis production and/or sale for adult (non-medical) use. Looking at outcomes of such reforms across multiple jurisdictions may help to identify outcomes that are inherent to non-criminal cannabis supply, as well as provide insight into the outcomes of specific regulation models.

Methods: We identified nine indicators of cannabis policy outcomes and aggregated them into three domains (social outcomes, outcomes in cannabis use, health-related outcomes). We assessed these outcomes across five jurisdictions with different models of regulating cannabis supply (Netherlands, Spain, U.S. states that legalized cannabis, Uruguay, and Canada). We used a three-level systematic literature review, prioritising studies with quasi-experimental design (i.e. comparative and longitudinal). We categorised the studies according to their design and the type of outcome (increase, decrease, or no outcome).

Results: Across long-standing as well as recent cannabis supply regimes, and across different models of cannabis supply, our review identified common outcomes: a decrease in cannabis-related arrests, an increase in adult (but not adolescent) cannabis use, and increase in healthcare utilization (not traffic-related). Negative health-related outcomes were most consistently found for the U.S. states that legalised cannabis for adult non-medicinal use (there were limitations to nuancing cannabis supply models across U.S. states). In the remaining jurisdictions (the Netherlands, Spain, Canada, Uruguay), the design or time-frame of the identified studies was limited, and studies on certain outcomes were lacking.

Conclusions: Regulating cannabis supply may be associated with benefits in the social area and with potential harms regarding public health; there may though be trade-offs depending on the choice of a cannabis regulation model. Jurisdictions may attempt to mix and match the present models of cannabis regulation to achieve the best ratio of benefits and harms. More research into the specific parameters influencing cannabis policy outcomes is needed.

Introduction

Several studies have reported on the outcomes of cannabis legalization to date (Smart & Pacula, 2019; Melchior et al., 2019; French et al., 2022). Scholars have suggested that each model of cannabis legalization/regulation might have different objectives, yield distinct

outcomes (Fischer et al., 2019; Kilmer, 2019; Hall, 2020a), or involve trade-offs (Queirolo, 2020a; Barata et al., 2022).

Countries in Europe and globally have recently been debating the legalization and regulation of their adult-use cannabis markets (Hofmann, 2022). The debate seems slowly shifting from whether cannabis legalization should be pursued, to announcements about the

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Table 1
Models of cannabis supply regulation.

	Duration of cannabis supply regulation	Regulatory framework	Subjects supplying cannabis	Advertising	Taxation	Harm reduction measures
Netherlands	50 years+	De-facto legal, regulated on federal as well as regional / municipal level for retail; production illegal	Coffee-shops; for-profit (retail only)	Not allowed	Only retail profits	Sales limit of 5 g
Spain	20 years+	Decriminalization and depenalization; self-regulation of supply	Cannabis social clubs (non-profit collectives)	Not allowed	VAT sometimes	Peer-delivered harm reduction in social clubs
U.S. states	10 years+	State-level legalization and supply regulations	For-profit licensed	Allowed (some restrictions towards youth)	State-level excise tax, sales tax, or both	n.a.
Uruguay	10 years	Country-level legalization and supply regulations	State-controlled producers; pharmacies (retail); non-profit collectives	Not allowed, packaging restrictions	VAT only	Peer-delivered harm reduction in social clubs, medical advice in pharmacies
Canada	5 years	Country-level legalization and supply regulations (production on federal and retail on provincial level)	For-profit licensed	Not allowed, packaging restrictions	Federal excise tax, province-level VAT (GST)	Lower risk cannabis use guidelines (Hudak et al., 2018)

NOTES: VAT – Value Added Tax (also referred to as GST – Goods and Services Tax).

detailed features of cannabis supply regulations. Examples of countries where cannabis regulation models for adult (non-medical) use that have recently been discussed include Germany (DW, 2022), Switzerland (Sabaghi, 2022), Malta (BBC, 2021), Colombia (Escobar, 2024), Mexico (Bolano, 2024), or the Czech republic (Sabaghi, 2023); the various proposals for cannabis regulation thereof include distribution via non-profit associations, state-controlled production, or sales in specialised stores or pharmacies.

In light of these debates, it is timely to explore the outcomes of the different approaches to regulating cannabis supply.

Models of regulating cannabis supply

In this analysis, we assessed five jurisdictions that adopted different models of cannabis supply regulation: The Netherlands which was the first country to “de-facto” allow regulated retail sales of cannabis in coffee shops while maintaining cannabis production illegal; Spain where cannabis decriminalization policy enabled production and dispensing of cannabis in social clubs which are operated by cannabis consumers in a “non-profit” and “self-regulated” manner; U.S. states where state-level legalization opened-up “for-profit” licensed production and sale of cannabis; Uruguay where country-level cannabis legalization created a “state-controlled” cannabis supply, allowing for cannabis social clubs at once; and finally, Canada, where a “hybrid approach” was taken by allowing “for-profit” licensed cannabis production and retail but also strictly prohibiting cannabis promotion and advertising. Details of how cannabis supply has been regulated in these jurisdictions are presented in Table 1.

Historically, there were two European countries that adopted some form of cannabis supply regulation. The first was The Netherlands in the 1970s and 1980s, which saw the emergence of infamous coffee shops (Korf et al., 2011). Rather than legalization of cannabis supply, their establishment has been “de-facto”, as it was guided by decriminalisation of cannabis use and personal possession and by non-enforcement policy for small-scale cannabis sales (up to 5 g), rather than by any change in cannabis classification by the law that would legalize cannabis supply overall (MacCoun, 2011). Tolerance towards coffee-shops has been a part of the broader policy aim to separate the markets with “soft” and “hard” drugs (Spapens et al., 2015). The first coffee-shop was opened in 1976 and their numbers notably increased in the 1980s, with tighter regulations being specified since 1996. Coffee shops are regulated by national guidelines as well as local jurisdictions (Korf et al., 2011). Regulations have included no advertising, no public nuisance, no sale of hard drugs, no large quantities of cannabis sold, and no sales to minors

(Boury et al., 2022). Given the “de-facto” legal status of cannabis in the Netherlands, and the EU-level restrictions preventing the application of value added tax to cannabis, there’s no specific tax applied to it (Grund & Breeksema, 2013). Also, it should be mentioned that the current supply regulations in the Netherlands pertain to retail distribution only; cannabis producers remain illegal (referred to as a ‘back door’ problem); a Controlled Cannabis Supply Chain Experiment of regulating cannabis production is currently in place in ten Dutch municipalities (Korf, 2020).

Second, a grassroots model of cannabis supply known as cannabis social clubs (CSCs) has been on the rise in Spain since the 1990s, especially in the provinces of Catalonia and the Basque Country (Barriuso, 2011). Like in the Netherlands, this form of cannabis supply also has not been stipulated by the law. Private consumption of cannabis is not a crime in Spain and sharing illicit drugs was not deemed a crime by several court rulings, leading to an interpretation that the production and distribution of cannabis among a closed network of consumers is not a crime in Spain (Muñoz & Soto, 2001). CSCs aim to provide a community-based drug-policy strategy for the reduction of risks associated with cannabis use (Obradors-Pineda et al., 2021). There had been attempts to regulate the cannabis social clubs, by demand from its constituents, but rulings of the federal court in Spain halted these attempts (Araña & Parés, 2020). Therefore, CSCs in Spain have remained “self-regulated” by the clubs and their federations; also, cannabis social clubs self-declare as “non-profit” (Belackova & Wilkins, 2018). Both the Spanish CSCs and the Dutch coffee shops cater to onsite consumption of cannabis. In the Spanish case, the fact that the CSCs are operated by peers and many are informed by responsible use principles has led to assertions that cannabis social clubs might enhance harm reduction practices (Belackova et al., 2016; Jansseune et al., 2019), although not all cannabis social clubs adhere to this model (Obradors-Pineda et al., 2021).

In 2012, despite the continuing federal prohibition of cannabis and several medicinal cannabis schemes in place, the U.S. states of Colorado and Washington first passed cannabis legalization and regulated cannabis supply for adult use via a public vote in 2012 (Matheson & Foll, 2020; Pardo, 2014). They were followed by twenty-one other U.S. states (Washington, California, Alaska, Arizona, Connecticut, Delaware, District of Columbia, Guam, Illinois, Maine, Maryland, Massachusetts, Michigan, Missouri, Montana, Nevada, New Jersey, New Mexico, New York, Oregon, Rhode Island, Virgin Islands, Vermont, and Virginia). The declared aims of adult-use cannabis legislations have been mainly to yield revenue for state budgets (Colorado) or to achieve social justice (Washington) (Obradovic, 2021). While differences exist between state regulations of cannabis supply, overall, the approach taken by U.S.

states has been characterised as “for-profit“ or “commercially-driven“ (Seddon, 2020). Such categorization stems from the fact that adult-use cannabis production and distribution in the states of the U.S. has been almost exclusively delivered by licensed private entities (Obradovic, 2021), with the federal constitution allowing for only a few restrictions on cannabis advertising (Carnevale et al., 2017). The “for-profit“ model, as adopted in the U.S. states, has been criticised for enabling extensive cannabis production, sales and advertising towards adults (Seddon, 2020; Fischer et al., 2020a).

A strikingly different cannabis legalization model was implemented in Uruguay in 2013 where an expert-designed model of cannabis supply regulation was implemented that ensured direct government involvement in the production and supply of adult-use cannabis (Seddon, 2020; Queirolo, 2020b). With the aim of curbing illicit international trade and improving public health, this model has been much more restrictive than the one adopted by the North-American counterparts (Queirolo, 2020b). The number of cannabis producers in Uruguay has been limited, and no purpose-built commercial outlets were allowed (individuals who register with the government can buy cannabis via pharmacies or in cannabis social clubs) (Fischer et al., 2020a; Hudak et al., 2018). Cannabis social clubs in Uruguay are heavily regulated by the state (Decorte et al., 2017). Cannabis in Uruguay is not allowed to be advertised and no specific tax other than VAT (value-added tax) has been applied to cannabis (Fischer et al., 2020b). The roll-out of cannabis supply regulations in Uruguay was gradual; home cultivation has been allowed since 2014, cannabis social clubs have operated since 2015, and the first sales in pharmacies started in 2017. Reportedly, there were difficulties with establishing the “state-controlled“ supply and the availability of legal cannabis remained low long after pharmacy sales started.

Thirdly, the federal government of Canada passed legalization and regulation of adult-use cannabis supply in 2018, described as “a hybrid model of both distinct public health and commercialization features“ (Fischer et al., 2020a). The aim of legally regulating cannabis in Canada has been to reduce cannabis use among the youth, reduce criminal profits, and protect public health (Seddon, 2020). Commercial producers have been licensed on the federal level, while regulation of the retail network has been left to the provincial governments. Some provinces have chosen to licence commercial retailers, others have used public companies or a combination of both public and private retailers (Fischer et al., 2020a; Myran et al., 2019; Department of Justice, Cannabis Legalization & Regulation, 2018). Legal cannabis sales in Canada began in 2018. Measures for reducing the harms of cannabis use beyond market regulation have been established in Canada, taking the

form of a guideline for low-risk cannabis use (Fischer et al., 2022). Also, there is an overall ban on advertising and mandated plain packaging of cannabis in place (Fischer et al., 2020b).

The majority of jurisdictions that introduced regulated cannabis supply also allowed home cultivation of cannabis. As this may account for only a small proportion of overall cannabis consumption (Belackova et al., 2020), we chose not to focus on home cultivation in this review.

In this study, we have assessed outcomes of the above-mentioned cannabis supply models. Looking across multiple jurisdictions, we aimed to identify outcomes that may be inherent to non-criminal cannabis supply, as well as provide insight into the outcomes of specific regulation models.

Methods

We identified nine indicators of cannabis legalization outcomes. The indicators were derived from available systematic reviews of studies that assessed the outcomes of cannabis legalization (Hall, 2020a; Scheim et al., 2020; Fischer et al., 2020c; Hall & Lynskey, 2020; Leyton, 2019; Parnes et al., 2018)), see Table 2. The indicators included in the present analysis were: (i) legal market participation; (ii) cannabis-related crime (arrests for cannabis possession, production, and trafficking, other crimes were included when we found such published studies), (iii) recent cannabis use in adults; (iv) recent cannabis use in adolescents; (v) problematic/intensive cannabis use; (vi) cannabis related hospitalizations (hospital admissions, i.e., inpatient); (vii) cannabis-related emergency presentations, and (viii) cannabis-related traffic accidents. We grouped these indicators into three objectives: 1 - social outcomes (legal market participation, cannabis-related crime), 2 - outcomes in cannabis use (recent cannabis use in adults, recent cannabis use in adolescents, problematic/intensive cannabis use), and 3 - health-related outcomes (cannabis related hospitalizations, cannabis-related emergency presentations, cannabis-related traffic accidents).

Literature review

In our literature review, we searched the following established databases: EBSCO (with Medline), Web of Science, and Scopus. We conducted this review in a three-step way, prioritising quasi-experimental (comparative and longitudinal) research over studies with lower potential to identify causality between cannabis policy and the selected outcomes.

Table 2
Outcomes of cannabis legalisation / regulated cannabis supply from systematic reviews.

	Fischer et al., 2019	Athanassiou, 2022	Fischer et al., 2021	Boury et al., 2022	Hall and Lynskey, 2020
I. Tax revenue	–	–	–	–	–
II. Legal market participation	X (sourcing cannabis)	–	X (sourcing cannabis)	X (sourcing cannabis)	–
III. Cannabis-related crime	–	–	–	–	–
IV. Cannabis use in adults	X	X	X	X	X
V. Cannabis use in adolescents	X	X	X	X	X
VI. Problematic/intensive cannabis use and treatment	X (cannabis use patterns & cannabis use disorders)	X	X	X	X
VII. Means of cannabis administration	X (modes of cannabis use)	–	X	X	–
VIII. Health outcomes of cannabis use	X (hospitalizations)	X (health service utilization)	–	X (hospitalizations)	X (cannabis- related hospitalizations)
IX. Traffic accidents	X (cannabis impaired driving)	X	X (cannabis impaired driving)	X (cannabis impaired driving)	X (road crashes)
OTHER CATEGORIES	Cannabis potency, harm to others, other substance use	Other crime, young adults use, alcohol, cigarette, and opioid use, suicide	–	Child hospitalizations	Price of cannabis, cannabis potency, Treatment seeking

Table 3
Outcomes of cannabis policy reform per jurisdiction – social outcomes.

Objective 1: Social outcomes					
	The Netherlands	Spain	USA	Uruguay	Canada
I. Tax revenue	NO STUDIES/DATA <i>Income tax: not available.</i>	NO STUDIES/DATA <i>Income tax: not available</i>	ADMINISTRATIVE <i>Income tax: not available</i>	NO STUDIES/DATA <i>Income tax: not available</i> <i>VAT: not available</i>	ADMINISTRATIVE <i>Income tax: not available</i>
	↓ VAT: No cannabis tax revenue. ↓ Excise tax: No cannabis tax revenue	↓ VAT: No cannabis tax revenue. ↓ Excise tax: No cannabis tax revenue.	↑ VAT + Excise tax for fiscal year 2022*: 2,934,900,000 USD (29,6 USD per capita) –Washington: 67 USD per capita –Maine: 13 USD per capita (Rotermann, 2020) –In 2021 Cannabis Excise Taxes exceeded Alcohol Excise Taxes in 7/11 states and Tobacco Excise Taxes in 2/11 states (Davis and Hegeman, 2022)	↓ Excise tax: No cannabis tax revenue.	↑ VAT + Excise tax for fiscal year 2021/2022: 924,512,000 USD (24.2 USD per capita) (Statistics Canada 2023)
II. Legal market participation	CROSS-SECTIONAL	CROSS-SECTIONAL	CROSS-SECTIONAL	CROSS-SECTIONAL	LONGITUDINAL
	✓ According to Global Drug Survey, 77 % purchase legally, 22 % buy from a dealer, 5 % grew it (Trautmann et al., 2013)	✓ In Spain, about 66% of 250,000 individuals who used cannabis in the past month estimated to be CSC members (Belackova and Wilkins, 2018)	✓ In Washington state, 63 % of estimated cannabis consumption from legal sources, 7 % from home cultivation (Caulkins et al., 2019)	✓ Estimates of 25 % cannabis consumers registered, up to 54 % use some legal cannabis; approx. 8 % of registered grow their cannabis legally and a similar number grow illegally (Queirolo, 2020)	↑ The proportion of people who reported using cannabis from legal sources increased from 23% in 2018 to 47% in 2019 and 68% in 2020; 8%, 11% and 14% respectively grew their own cannabis (Rotermann, 2020)
				LONGITUDINAL ↑ The number of cannabis registrations in Uruguay increased from 34,108 in 2018 to 74,891 in 2022 (IRCCA 2022); monthly sales in pharmacies remained stable (IRCCA 2022)	
III. Cannabis-related crime	COMPARATIVE	COMPARATIVE	LONGITUDINAL & COMPARATIVE	LONGITUDINAL	LONGITUDINAL
	↓ Between 2017 and 2021, the mean proportion of cannabis-related crimes on all crimes was 41% in the Netherlands compared to 71% in the neighbouring Belgium (EMCDDA 2022a, EMCDDA 2022b)	↓ Between 2017 and 2021, the mean proportion of cannabis-related crimes on all crimes was 80% in Spain compared to 88% in the neighbouring Portugal (EMCDDA 2022a, EMCDDA 2022b)	↓ In states that implemented legalization, the arrest rate in 2008 was 599.2 for Black adults and 210.9 for White adults. The corresponding numbers in 2019 were 38.0 and 15.9, respectively (Sheehan et al., 2021) ↓ Combining county-level difference-in-differences and spatial regression discontinuity designs, we find that the policy caused a significant reduction in rapes and property crimes in Washington (Dragone et al., 2019) ↓ An additional dispensary in a neighbourhood leads to a reduction of 17 crimes per month per 10,000 residents (Brinkman and Mok-Lamme, 2019) ⇔ Marijuana legalization and sales have had minimal to no effect on major crimes in Colorado or Washington (Lu et al., 2021) or across the U.S. states that legalized it overall (Maier et al., 2017) ↑ Cannabis allegation rates increased 28% among all youth and 32% among cannabis-using youth after legalization (Firth et al., 2020)	↓ 22% of all drug-related crimes; 34% of ↓ all possession-related drug crimes between 2010 and 2017 (IRCCA 2019)	⇔ There was also a lack of evidence for spillover effects of cannabis legalization on adult property or violent crimes for youth (Callaghan et al., 2023) or adults (Callaghan et al., 2023) ↓ 68% of drug crimes that pertain to cannabis (from 136 to 45 per 100 inhab.; continued trend since pre-legalization); 44% decrease of all drug crimes (from 43% to 24%); 82% ↓ cannabis possession crimes (from 75% to 13%) (Statistics Canada, 2020) ↓ Implementation of the Cannabis Act was associated with decreases in adult police-reported cannabis-related offenses: females, –13.2 daily incidents (95% CI, –16.4; –10.1; p < 0.001) – a reduction of 73.9% [standard error (se), 30.6%]; males, –69.4 daily offenses (95% CI, –81.5; –57.2; p < 0.001) – a drop of 83.2% (se, 21.2%) (Callaghan et al., 2023)

*States covered based on data availability: Alaska, Arizona, California, Colorado, Illinois, Maine, Massachusetts, Michigan, Montana, Nevada, New Jersey, New Jersey Oregon, Vermont, Washington

NOTE: VAT – Value Added Tax; RML – Recreational Marijuana Laws, CSC – cannabis social clubs, CI – confidence interval.

Table 4
Outcomes of cannabis policy reform per jurisdiction – cannabis use.

Objective 2: Outcomes in cannabis use					
	The Netherlands	Spain	USA	Uruguay	Canada
IV. Recent cannabis use in adults	<p>COMPARATIVE</p> <p>⇔ Survey among regular cannabis users in Amsterdam and San Francisco found no evidence of the Dutch cannabis policy influencing cannabis use (Reinarman et al., 2004)</p> <p>↑ Comparison of available studies on cannabis use between Netherlands and the U.S. suggested that commercial promotion and sales in coffee-shops may have increased cannabis prevalence in the Netherlands (MacCoun and Reuter, 2001)</p>	<p>LONGITUDINAL</p> <p>↑ In Catalonia, last month use among adults went from 8.3% to 11.9% between 2001 and 2017 (EDADES 2019); comparison with Spanish provinces where CSCs are not common wasn't available</p>	<p>LONGITUDINAL & COMPARATIVE</p> <p>↑ A significant impact in Washington (Miller et al., 2017) and Colorado (Wallace et al., 2020) in (Athanassiou et al., 2022)</p> <p>↑ Only in ages 25–34 (aOR = 1.340, 95% CI: 1.021–1.758) and ages 50+ (aOR = 1.623, 95% CI: 1.192–2.208) (Kim et al., 2021) in (Athanassiou et al., 2022)</p> <p>↑ Among >26 year olds from 5.7% to 7.1% (Cerdá et al., 2020) in (Athanassiou et al., 2022)</p> <p>↑ A significantly greater transition from non-use to use and to weekly use in legalizing states (Gunadi et al., 2022)</p>	<p>LONGITUDINAL</p> <p>↑ Last month use from 4.9% in 2011 to 8.9% in 2018 (NOTE: continued growth since pre-legalization) (IRCCA 2019)</p>	<p>LONGITUDINAL</p> <p>↑ Use in past 3 months from 14.9% (95% CI: 14.1, 15.7) in 2018 to 16.8% (95% CI: 16.1, 17.6) in 2019, to 20.0% (95% CI: 18.3, 21.8) in 2020; particularly in 18–24 y olds (Rotermann, 2021)</p>
	<p>LONGITUDINAL</p> <p>↑ According to general population surveys, cannabis use in the Netherlands has been on increase since 1980s, following coffee-shop expansion [171]</p>				
V. Recent cannabis use in adolescents	<p>LONGITUDINAL & COMPARATIVE</p> <p>⇔ NL was among five countries out of 38 where partial prohibition was associated with higher odds of regular cannabis use (OR = 2.39, p = .016) (Shi et al., 2015); however, re-examination of the (Shi et al., 2015) analysis found no association between policy 'liberalization' and adolescent cannabis use (Stevens, 2019)*</p>	<p>LONGITUDINAL & COMPARATIVE</p> <p>⇔ Interrupted time-series analysis of use among young people in Europe (Spain included alongside 10 other EU countries) found no impact of cannabis policy changes (Gabri et al., 2022)</p> <p>⇔ Ibid * for Spain</p>	<p>LONGITUDINAL & COMPARATIVE</p> <p>↓ A small significant decline in the level of use in RML states (incidence rate ratio 0.844, 95% confidence interval [0.720 - 0.989 (Coley et al., 2021) in (Athanassiou et al., 2022)</p> <p>⇔ No effect of RML on use among college students in Oregon (Kerr et al., 2017, Kerr et al., 2018) in (Athanassiou et al., 2022)</p> <p>⇔ No association between cannabis use in youth and RML (Kim et al., 2021)</p> <p>↑ In Washington, 8th and 10th graders increased by 2.0% and 4.1%, respectively, in states with no RML decreased by 1.3% and 0.9% over the same period (Cerdá et al., 2017) in (Athanassiou et al., 2022)</p> <p>↑ Significantly more transition from non-use to use but not to weekly use in legalizing states (Gunadi et al., 2022)</p>	<p>LONGITUDINAL</p> <p>⇔ No increase in (risky) cannabis use among youth (Rivera-Aguirre et al., 2022)</p>	<p>LONGITUDINAL</p> <p>⇔ No significant difference in youth use in past 3 months pre-and post-legalization (Rotermann, 2021)</p> <p>⇔ Cannabis legalization has not (yet) been followed by pronounced changes on youth cannabis use (Zuckermann et al., 2021)</p> <p>↑ Past 12 months increased among younger students in grades 7-9 (e.g., ages 13 – 15; from 5.5% [95% CI: 5.0, 6.1] in 2016/17 to 7.0% [95% CI: 6.2, 7.8] in 2018/19 (Fischer et al., 2021)</p>

(continued on next page)

Table 4 (continued)

Objective 2: Outcomes in cannabis use					
	The Netherlands	Spain	USA	Uruguay	Canada
VI. Problematic/intensive cannabis use	COMPARATIVE ↔ Prevalence of daily cannabis use in the general population was estimated as 0.8%, which was in a higher range among European countries but lower than in Belgium, Portugal or the UK (Thanki et al., 2012)	NO STUDIES/DATA	LONGITUDINAL & COMPARATIVE ↔ No increase in youth and young adults frequency of use (Cerdá et al., 2020) in (Athanassiou et al., 2022) ↑ Increase in past-year CUD in adults (from 0.90 to 1.23%), and also in youth (OR 1.25; 95%, confidence interval (CI) 1.01–1.55) (Cerdá et al., 2020) in (Athanassiou et al., 2022) ↑ Faster increase in cannabis use in past 30 days in states that legalised cannabis, differential time trend F (1)= 2.008 (p = 0.045) (Weinberger et al., 2022)	NO STUDIES/DATA	LONGITUDINAL ↔ „No substantive signals of increases in daily- or near-daily use among current cannabis users” (Fischer et al., 2021)

NOTE: NL – The Netherlands; RML – Recreational Marijuana Laws, CSC – cannabis social clubs, CI – confidence interval.

Firstly, we used search terms related to cannabis policy (“cannabis legalization”, “cannabis market” AND “regulation”), its outcomes (“cannabis use”, “cannabis related hospitalizations”, “cannabis AND tax revenue” etc.), combined with terms referring to quasi-experimental research design (“cohort study”, “longitudinal and comparative”, “difference in differences”). We ran this search for each of the study jurisdictions. Finally, we populated fields in the Tables 3–5 with findings from this search.

Secondly, we ran the same search to populate cells in Tables 3–5 where the first search did not yield any results. This time, we did not specify the study method. For Spain and the Netherlands, we included research that wasn’t specifically assessing the outcomes of cannabis law reform considering the reforms occurred historically (i.e., we included studies that assessed cannabis-use trends in those countries and/or compared them to other jurisdictions, regardless of their timeframe, and generally in the absence of pre- and post- design). We populated the fields in Tables 3–5 with relevant studies that were not found in the first search.

Thirdly, we conducted a search of the internet and grey literature in areas where neither the first nor the second search yielded results. For Spain and The Netherlands, this also included searching the EMCDDA statistical bulletin for any relevant indicators over time; secondary calculations from this bulletin were performed when necessary and comparisons with neighbouring countries were made (in particular, we calculated the proportion of cannabis-related crimes among all drug-related crimes and the proportion of cannabis-related ED presentations among all toxicology presentations). In this way, we ensured that the best available knowledge regarding the outcomes of cannabis supply regulations was considered, but also that no potentially relevant evidence was left out. All studies and materials published until September 2023 (date of this search) were included.

Categorising research

We categorised all the identified research as “cross-sectional”, “comparative”, “longitudinal” or “longitudinal and comparative”. “Administrative” data was also included for tax revenue information. Studies that were “longitudinal and comparative” were considered the highest level of evidence because of their ability to separate the

outcomes of a policy change from any trends that would occur within that jurisdiction in the absence of the change. We also categorised the study findings based on whether they suggested an increase in an outcome (marked as “↑” in Tables 3–5), a decrease (“↓”), or no change (“↔”) associated with cannabis supply regulation in quasi-experimental studies or longitudinal studies (when quasi-experimental studies were not available). In comparative studies, the findings were categorised as higher (“↑”), lower (“↓”) or the same (“↔”) compared to jurisdictions without such regulation.

Results

First, we outline the studies and the type of evidence identified in our literature search. Second, we discuss the findings of the studies per domain and the respective indicators.

Identified studies

Overall, we included 72 relevant studies from the literature search. The first level review yielded nine studies adhering to a quasi-experimental study design. This search also helped identify twenty-two additional studies from systematic literature reviews (Athanassiou et al., 2022; Windle et al., 2022), yielding a total of 36 quasi-experimental studies.

The second level search of scientific databases yielded 36 relevant studies that were either longitudinal or comparative. The third level search of grey literature yielded 12 sources: 6 were classified as longitudinal or comparative and 3 studies used administrative data. Comparative or longitudinal study designs, or a combination of both, were available for all indicators except for assessing proportion of legal market with cannabis (and for tax revenue which used administrative data).

Study design per jurisdiction

Each jurisdiction in this study had a different type of evidence available to assess the outcomes of cannabis supply regulation. In The Netherlands, only one study adhered to a longitudinal and comparative (i.e., quasi-experimental) design (Stevens, 2019); all the remaining

Table 5
Outcomes of cannabis policy reform per jurisdiction – health-related outcomes.

Objective 3: Health-related outcomes					
	The Netherlands	Spain	USA	Uruguay	Canada
VII. Cannabis-related hospitalizations	LONGITUDINAL	LONGITUDINAL	LONGITUDINAL & COMPARATIVE	LONGITUDINAL	LONGITUDINAL
	<p>↑ First-time cannabis treatment admissions (per 100 000 inhabitants) rose from 7.08 to 26.36 from 2000 to 2010, and then decreased to 19.82 in 2015. Cannabis use was associated with treatment entry at lags of 0–9 years, with the strongest association at 5 years, $b = 0.370$ (0.317–0.424), $p < 0.0001$ (Freeman et al., 2018)</p>	<p>↑ In Catalonia, 4 fold steady increase in demand for cannabis treatment was found; from 337 cannabis-related treatment cases in 1997 (Gencat, Pla de Salut de Catalunya 2002) to 1705 in 2017 (Gencat, Sistema d'informacio sobre drogodependencies en Catalunya, Informe Annual 2019); comparison with Spanish provinces where CSCs are not common wasn't available</p>	<p>↑ Adjusted odds of a cannabis-related hospitalization (CUD, poisoning) in adolescents in RML states (odds ratio 1.03, 95% confidence interval 1.02–1.03) between 2008 and 2019 (Masonbrink et al., 2021) in (Athassiou et al., 2022)</p> <p>↑ In Colorado compared with New York and Oklahoma, cannabis-related hospitalizations increased (risk ratio (RR) 1.27, 95% CI 1.26 to 1.28 and RR 1.16, 95%CI 1.15 to 1.17 respectively (Delling et al., 2019) in (Athassiou et al., 2022);</p> <p>↑ In Colorado, increasing recreational dispensaries were associated with increases in cannabis pregnancy hospitalizations (1.02, CI: 1.00,1.04) (Wang et al., 2022)</p>	<p>↑ Drug treatment requests related to cannabis (from 5.7 in 2013 to 8.3 in 2018; cross-sectional, considered not significant) (IRCCA, 2019)</p>	<p>⇔ In boys aged 10 to 14 years, cannabis-related hospitalization rates increased from 5.2 per 100,000 one year before legalization [95% confidence interval (CI) 2.9–9.3] to 9.5 per 100,000 after legalization (95% CI 6.2–14.6), however, the increase was not statistically significant. There was no increase in cannabis-related hospitalizations among girls or boys aged 15 to 19 years (Auger et al., 2021).</p> <p>↑ Overall, the age- and sex-standardized rate of hospitalizations increased 1.62 times between January 2015 (3.99 per 100,000 individuals) and March 2021 (6.46 per 100,000). Commercialization and the COVID-19 pandemic were associated with an immediate increase of 0.83 (95% CI, 0.30 to 1.30) hospitalizations due to cannabis (Myran et al., 2023)</p> <p>↑ The proportion of cannabis-related ED visits with hospitalization increased significantly after the introduction of edibles (122 visits [38.5%] during period 2 vs 29 visits [23.4%] during period 1 and 20 visits [24.7%] during the pre-legalization period; $P = .002$) (Myran et al., 2022).</p>

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Table 5 (continued)

Objective 3: Health-related outcomes					
	The Netherlands	Spain	USA	Uruguay	Canada
VIII. Cannabis-related emergency presentations	<p>COMPARATIVE</p> <p>⇔ 28% of drug-related presentations in the Dutch cities (2018 – 2021) were for cannabis, similar to 26% in neighbouring Belgium (EMCDDA 2023)</p>	<p>COMPARATIVE</p> <p>↑ 36 % of drug-related presentations in the Spanish cities (2017 – 2021) were for cannabis, compared to 24% in neighbouring France (EMCDDA 2023)</p>	<p>LONGITUDINAL & COMPARATIVE</p> <p>↑ Cannabis commercialization was associated with 5.06–5.80 more cannabis poisoning exposures per 1,000,000 population per quarter (67–77% increase relative to the pre-legalization average) (Shi and Liang, 2020) in (Athanassiou et al., 2022)</p>	<p>NO STUDIES/DATA</p>	<p>LONGITUDINAL</p> <p>⇔ There was no difference in overall visits to the ED after legalization (2.44 vs 2.94 visits per 1,000 visits, $p = 0.27$). (Baraniecki et al., 2021)</p> <p>⇔ There was no difference in the rate of positive cannabinoid screen results before and after legalization (22 [25%] v. 22 [22%]) (Ball et al., 2021)</p> <p>⇔ In an ITS, no evidence of increases in health service use or incident cases of psychotic disorders over the short-term (17 months) post cannabis legalization (Anderson et al., 2024)</p> <p>⇔ The initial legalization period was not associated with changes in rates of ED visits for cannabis-induced psychosis. The commercialization period was associated with an immediate increase in rates of ED visits for cannabis-induced psychosis (IRR 1.30, 95% CI 1.02–1.66) and no gradual monthly change; immediate increases were seen only for youth above (IRR 1.63, 1.27–2.08, ages 19–24) but not below (IRR 0.73 95%CI 0.42–1.28 ages, 15–18) (Myran et al., 2023)</p> <p>⇔ In an interrupted time-series analysis (ITS), the level of cannabis-related ED presentations increased post-legalisation by 12%, but the pre-legalization increasing trend attenuated to being stable over time (Myran et al., 2022).</p> <p>↑ Presentations for unintentional ingestions of cannabis increased in children (IRR: 1.77, 95% confidence interval [CI]: 1.42 to 2.20 and RR: 1.24, 95% CI: 1.05 to 1.47, respectively) and older adolescents (IRR: 1.36, 95% CI: 1.07 to 1.71 and RR: 1.48, 95% CI: 1.21 to 1.81, respectively) (Yeung et al., 2021)</p> <p>↑ The mean quarterly rate of acute care for cannabis use during pregnancy increased from 11.0 per 100 000 pregnancies before legalization to 20.0 per 100 000 pregnancies after legalization (incidence rate ratio [IRR] 1.82, 95% confidence interval [CI] 1.44–2.31) (Myran et al., 2023)</p> <p>↑ Post-legalization increase of 14.7 (95% confidence interval [CI] 5.0; 24.3, $p < 0.01$) weekly youth cannabis-related disorder/poisoning presentations to Ontario/Alberta ED of 20.0% (95% CI 6.2%; 33.9%) (Callaghan et al., 2023)</p> <p>↑ ED presentation for cannabis in Alberta increased in 43 per month (95% confidence interval)[129]; in Ontario, adults 25–64, particularly women, had increased ED presentations for cannabis (Kim et al., 2022)</p>

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Table 5 (continued)

Objective 3: Health-related outcomes					
	The Netherlands	Spain	USA	Uruguay	Canada
IX. Traffic accidents	<p>COMPARATIVE</p> <p>↓ In total, 535 injured drivers were included in the study (BE: 348; NL: 187). In the Netherlands almost no positive findings for cannabis were recorded (0.5%), in Belgium this was 7.6%. In previous studies, 6% of Belgium and 3% of Dutch injured drivers tested positive for cannabis (Legrand et al., 2012) and was the lowest among six European countries (Legrand et al., 2013)</p> <p>⇒ A review of studies showed that the proportion of drivers in emergency departments who tested positive for cannabis was similar across Spain, Netherlands, and Italy (all 12%), although was higher than in Sweden and Greece (4%) or Norway (6%) (Santamarina-Rubio et al., 2009, Verstraete et al., 2014)</p> <p>↓ During random testing of vehicle drivers in Belgium and the Netherlands, THC alone was found in 1.67% [1.34, 2.07] of Dutch drivers and only in 0.35% [0.19, 0.64] of drivers in Belgium (Houwing et al., 2012)</p>	<p>COMPARATIVE</p> <p>⇒ A review of studies showed that the proportion of drivers in emergency departments who tested positive for cannabis was similar across Spain, Netherlands, and Italy (all 12%), although was higher than in Sweden and Greece (4%) or Norway (6%) (Santamarina-Rubio et al., 2009, Verstraete et al., 2014)</p> <p>↑ Roadside testing in the DRUID project (2007 – 2011) showed the highest prevalence of cannabis use among drivers in Spain from among 13 European countries (Houwing et al., 2012)</p>	<p>LOGITUDINAL & COMPARATIVE</p> <p>A systematic review of studies assessing effect of cannabis legalization on traffic outcomes (Windle et al., 2022) found nine relevant studies with quasi-experimental design assessing U.S. states:</p> <p>⇒ Four studies found no association: RML not associated with motor vehicle crashes (Fowles and Loeb, 2021); ANCOVA analysis indicated no difference between Washington State and other non-legalized states in traffic fatalities involving cannabinoids (Hansen et al., 2020); synthetic control groups had similar changes in marijuana-related traffic fatality rates as Colorado and Washington (Hansen et al., 2020); effects were similar in both legalizing (step: 0.90, $P < 0.001$; trend: -0.05, $P = 0.007$) and neighbouring sites (step: 1.15, $P = 0.005$; trend: -0.06, $P = 0.001$) (Lane and Hall, 2019); there were no effects of legalization, except that policing of DUI increased in Washington and Colorado in 2013 (Miller, 2018)</p> <p>↑ Five studies found an effect of RMLs: the combined effect of legalization and retail sales was a 5.8% increase in injury crash rates and a 4.1% increase in fatal crash rates (Farmer et al., 2022); increase of 2.1 (95%CI, 1.2-2.9; $P < .001$) traffic fatalities per billion vehicle miles travelled (BVMT) in experimental states relative to control states post-commercialization (Kamer et al., 2020); increased number of marijuana-related crashes after all types of the marijuana law changes except for medicinal (Lee et al., 2018); increased rates of fatal motor vehicle collisions (incidence rate ratio [IRR] 1.15, 95% confidence interval [CI] 1.06–1.26) and associated deaths (IRR 1.16, 95% CI 1.06–1.27) (Windle et al., 2021); increase in THC-positive drivers involved in fatal crashes post RML in Washington, but no further increase after cannabis retail shops opened in 2014 (Woo, 2019)</p>	<p>LONGITUDINAL & COMPARATIVE</p> <p>⇒ no association between the total number of registrations and traffic crashes with injuries ($\beta = -0.007$; $P = 0.398$; 95% CI = -0.023, 0.01) (Kilmer et al., 2022)</p> <p>↑ association between the number of individuals registered as self-cultivators and the number of traffic crashes with injuries ($\beta = 0.194$; $P = 0.008$; 95% CI = 0.058, 0.329)[125]</p> <p>LONGITUDINAL</p> <p>↑ 52.4% increase in light motor-vehicle drivers' fatality rate than what the trend would be in absence of legalization, but this was not observed for motorcyclists (Nazif-Munoz et al., 2020).</p>	<p>LONGITUDINAL</p> <p>⇒ Implementation of the Cannabis Act was not associated with evidence of significant post-legalization changes in traffic-injury ED visits in Ontario or Alberta among all drivers or youth drivers (Callaghan et al., 2021)</p> <p>⇒ no increases in self-reported cannabis use before driving (Rotermann, 2021)</p> <p>↑ Before legalization, a THC level greater than 0 was detected in 9.2% of drivers, a THC level of at least 2 ng per milliliter in 3.8%, and a THC level of at least 5 ng per milliliter in 1.1%. After legalization, the values were 17.9%, 8.6%, and 3.5%, respectively (Brubacher et al., 2022)</p>

NOTE: NL – The Netherlands; BE – Belgium; ; RML – Recreational Marijuana Laws; CSC – cannabis social clubs; CI – confidence interval; CUD – cannabis use disorder; THC –tetrahydrocannabinol.

evidence was either longitudinal (Freeman et al., 2018), comparative (EMCDDA, 2022a; EMCDDA, 2022b; Reinerman et al., 2004; MacCoun & Reuter, 2001; Thanki et al., 2012; EMCDDA, 2023; Legrand et al., 2012; Legrand et al., 2013; Santamariña-Rubio et al., 2009; Verstraete et al., 2014; Houwing et al., 2012), or cross-sectional (Trautmann et al., 2013). This was similar for Spain, with only two studies employing a longitudinal and comparative design (Stevens, 2019; Gabri et al., 2022); one Spanish study was cross-sectional (Belackova & Wilkins, 2018), two studies were longitudinal (EDADES, 2019; Gencat, Pla de Salut de Catalunya, 2002; Gencat, Sistema d'informació sobre drogodependències en Catalunya, Informe Annual, 2019), and all remaining sources for Spain used comparative study design (EMCDDA, 2022a; EMCDDA, 2022b; EMCDDA, 2023; Santamariña-Rubio et al., 2009; Verstraete et al., 2014; Houwing et al., 2012). On the other hand, twenty-nine studies from U.S. states mainly adhered to quasi-experimental design (Lu et al., 2021; Maier et al., 2017; Sheehan et al., 2021; Dragone et al., 2019; Brinkman & Mok-Lamme, 2019; Fowles & Loeb, 2021; Hake, 2019; Hansen et al., 2020; Lane & Hall, 2019; Miller, 2018; Farmer et al., 2022; Kamer et al., 2020; Lee et al., 2018; Windle et al., 2021; Woo, 2019; Miller et al., 2017; Wallace et al., 2020; Kim et al., 2021; Cerdá et al., 2020; Coley et al., 2021; Kerr et al., 2017; Kerr et al., 2018; Cerdá et al., 2017; Masonbrink et al., 2021; Delling et al., 2019; Wang et al., 2022; Shi & Liang, 2020; Gunadi et al., 2022; Weinberger et al., 2022). Of these, twelve (Miller et al., 2017; Wallace et al., 2020; Kim et al., 2021; Cerdá et al., 2020; Coley et al., 2021; Kerr et al., 2017; Kerr et al., 2018; Cerdá et al., 2017; Masonbrink et al., 2021; Delling et al., 2019; Wang et al., 2022; Shi & Liang, 2020) were retrieved from a systematic review of cannabis use (Athassiou et al., 2022) and ten studies (Fowles & Loeb, 2021; Hake, 2019; Hansen et al., 2020; Lane & Hall, 2019; Miller, 2018; Farmer et al., 2022; Kamer et al., 2020; Lee et al., 2018; Windle et al., 2021; Woo, 2019) came from a systematic review on traffic accidents (Windle et al., 2022). The only cross-sectional analysis for the U.S. states pertained to the proportion of the legal market with cannabis (Caulkins et al., 2019); administrative data on tax revenue were available (Auxier & Ahri, 2022; Davis & Hegeman, 2022; Rotermann, 2020).

Longitudinal design, generally including a pre- and post- analysis, was used in nearly all studies in Uruguay (IRCCA, 2019; Rivera-Aguirre et al., 2022; Nazif-Munoz et al., 2020; IRCCA, 2022) and Canada (Myran et al., 2019; Rotermann, 2020; Callaghan et al., 2023a, 2023b; Statistics Canada, 2020; Firth et al., 2020; Rotermann, 2021; Zuckermann et al., 2021; Fischer et al., 2021; Auger et al., 2021; Baraniecki et al., 2021; Ball et al., 2021; Kim et al., 2022; Callaghan et al., 2021; Callaghan et al., 2023c; Anderson et al., 2024; Brubacher et al., 2022; Myran et al., 2022a,b; Myran et al., 2023a, 2023b, 2023c; Yeung et al., 2021). This was in the absence of suitable jurisdictions to compare the policy outcomes in these two countries with. One recent study in Uruguay tried to compensate for this limitation by using quasi-experimental design to compare traffic accidents across different localities in Uruguay, stratified by the number of official registrations to legally acquire cannabis (Kilmer et al., 2022). Administrative data were used to determine tax revenue in Canada (Statistics Canada, 2023) and the proportion of the legal market with cannabis in Uruguay (Queirolo, 2020b).

Findings by objective

Our analysis identified both increases, decreases, and no outcome in nine indicators, across five jurisdictions. Below, we discuss the findings for each objective.

Objective 1: Social outcomes

We focused on income tax, VAT, and other taxes related to cannabis sales as potential benefits of legalization. We identified tax revenue for the U.S. states (Auxier & Ahri, 2022; Davis & Hegeman, 2022) and Canada (Statistics Canada, 2023), while in the remaining jurisdictions, no tax revenue was noted. Regarding legal market participation, all jurisdictions except for Uruguay (Queirolo, 2020b) estimated more than

50 % of cannabis used (or of people using cannabis) from the regulated market. This was the case in the Netherlands (Trautmann et al., 2013), Spain (Belackova & Wilkins, 2018), Washington (Caulkins et al., 2019), and Canada (Rotermann, 2020).

When it comes to cannabis-related crime, we found evidence of reduced cannabis-related offences in all five jurisdictions - the Netherlands and Spain (EMCDDA 2022a, EMCDDA 2022b), the U.S. states (Sheehan et al., 2021), Uruguay (IRCCA, 2019), and Canada (Callaghan et al., 2023a, 2023b; Statistics Canada, 2020). However, in the U.S. state of Oregon, one quasi-experimental study also found an increase in youth cannabis allegations following cannabis legalization (Firth et al., 2020).

As for other types of crime, these were examined in two jurisdictions only: U.S. states (Lu et al., 2021; Maier et al., 2017) and Canada (Callaghan et al., 2023a, 2023b); no significant effects were found in these jurisdictions. Two additional studies from the U.S. found a significant decrease in certain types of crime following legalization of cannabis for adult use (Dragone et al., 2019; Brinkman & Mok-Lamme, 2019).

Objective 2: Outcomes in cannabis use

All studies related to Objective 2 (outcomes in cannabis use) found either an increase in cannabis use or observed no change. Only one study from the U.S. observed a decline in adolescent cannabis use following adult-use cannabis legalization (Coley et al., 2021).

Across all jurisdictions, studies demonstrated an increase in recent cannabis use among adults, including in the Netherlands (MacCoun & Reuter, 2001), Spain (EDADES 2019), U.S. states that regulated cannabis supply (Kim et al., 2021; Cerdá et al., 2020) (particularly in Washington (Miller et al., 2017) and Colorado (Wallace et al., 2020)), Uruguay (IRCCA, 2019), and Canada (Rotermann, 2021) (see Table 4 for details). One additional study suggested no impact of the Dutch cannabis policy on adult cannabis use (Reinerman et al., 2004).

When it comes to cannabis use among adolescents, there were three papers showing an increase – two in the U.S. (Cerdá et al., 2017; Gunadi et al., 2022) and one in Canada (Fischer et al., 2021). In each of the U.S. (Kim et al., 2021) and Canada (Rotermann, 2021; Zuckermann et al., 2021), we also found studies suggesting no association between cannabis legalization and the rates of cannabis use among youth. Indeed, cannabis use among youth did not increase in Uruguay post-legalization (Rivera-Aguirre et al., 2022). Studies showed that cannabis use among youth wasn't significantly different in The Netherlands (Stevens, 2019; Shi et al., 2015) or in Spain (Stevens, 2019; Gabri et al., 2022) when compared to other jurisdictions.

Regarding daily/weekly/intensive cannabis use being associated with cannabis legalization, U.S. states (Athassiou et al., 2022; Gunadi et al., 2022; Weinberger et al., 2022) were the only jurisdiction where such conclusive evidence was found. For The Netherlands, a study showed the rate of such use was lower than in several other European countries (Thanki et al., 2012). A review paper from Canada suggested that intensive cannabis use did not increase post-legalization (Fischer et al., 2021). For Uruguay and Spain, no research was available on trends in problematic cannabis use. However, in the Netherlands, Spain, and Uruguay, admissions into treatment for cannabis dependence had increased over time. This is reported below, under Objective 3 (Health-related outcomes).

Objective 3: Health-related outcomes

We found studies showing an increase in cannabis-related hospitalizations in all jurisdictions except for Canada. In particular, studies pointed to increased demand for treating cannabis use disorders in The Netherlands (Freeman et al., 2018), Spain (Gencat, Pla de Salut de Catalunya, 2002), and Uruguay (IRCCA, 2019). Studies showing an increase in cannabis-related hospitalizations not limited to cannabis treatment came from U.S. states (Masonbrink et al., 2021) (particularly Colorado (Athassiou et al., 2022; Wang et al., 2022)). Only one study

did not suggest an increase in cannabis-related hospitalizations; it focused on Canadian youth and found no significant change post-legalization (Auger et al., 2021); yet two other studies from Canada suggested an increase in cannabis-related hospitalisations (Myran et al., 2022a; Myran et al., 2023a).

We also found studies showing an increase in cannabis-related emergency presentations in all jurisdictions except for the Netherlands. An increase in cannabis-related emergency presentations was recorded in the U.S. among adults (Shi & Liang, 2020) and children (Wang et al., 2016). According to the EMCDDA Statistical Bulletin, there was a notably higher proportion of cannabis-positive toxicology reports in Spanish emergency departments compared to those in France (EMCDDA, 2023). For Canada, five studies demonstrated an increase in emergency presentations post- cannabis legalization, particularly in Ontario and Alberta (Kim et al., 2022; Callaghan et al., 2023c; Myran et al., 2022a; Myran et al., 2023a, Myran et al., 2023b; Yeung et al., 2021; Yeung et al., 2020).

However, other Canadian studies did not find a significant increase in cannabis-positive hospitalisations (Auger et al., 2021) or ED presentations (Baraniecki et al., 2021; Ball et al., 2021) after cannabis was legalized and there were three studies showing mixed findings depending on the time-frame and whether immediate increases or long-term trends were considered (Anderson et al., 2024; Myran et al., 2023b; Myran et al., 2022b). For the Netherlands, EMCDDA data showed lower rates of cannabis-positive toxicology reports compared to the neighbouring Belgium (EMCDDA, 2023). We found no studies examining cannabis-related emergency presentations in Uruguay.

When it comes to road traffic accidents, we found studies suggesting no association between cannabis policy and traffic accidents in each of the five jurisdictions, i.e. the Netherlands (Santamariña-Rubio et al., 2009; Verstraete et al., 2014), Spain (Santamariña-Rubio et al., 2009); Verstraete et al., 2014), the U.S. states (Fowles & Loeb, 2021; Hake, 2019; Hansen et al., 2020; Lane & Hall, 2019; Miller, 2018), Uruguay (Kilmer et al., 2022), and Canada (Rotermann, 2021; Callaghan et al., 2021). Moreover, we found two studies suggesting a decreased cannabis-related risk for traffic accidents in the Netherlands (Legrand et al., 2012; Legrand et al., 2013), compared to other European countries.

On the contrary, we also found studies showing an increase in traffic accidents related to cannabis in all jurisdictions. There were three such studies from U.S. states (Kamer et al., 2020; Lee et al., 2018; Windle et al., 2021; Woo, 2019). A study including the Netherlands and Spain (Houwing et al., 2012) found a higher proportion of cannabis-positive roadside drug tests (actual traffic accidents were not examined) and a study from Canada showed higher proportions of cannabis positive tests (Brubacher et al., 2022). Two studies in Uruguay pointed to a higher proportion of traffic accidents related to its cannabis policy (Nazif-Munoz et al., 2020; Kilmer et al., 2022), but these were all traffic accidents – not just cannabis-related ones. An overview is provided in Table 5.

Discussion

This study assessed the outcomes of regulated cannabis markets across nine indicators, grouped into three domains (social outcomes, outcomes in cannabis use, and health-related outcomes). Overall, our findings corroborate those of previous studies and reviews, which found increases in adult cannabis use, limited impact on adolescent use, increases in cannabis-related health presentations, and limited evidence on the impact on traffic accidents (Athanasios et al., 2022; Fischer et al., 2021; Hall et al., 2023; Boury et al., 2022). By encompassing more jurisdictions, and considering the level of study design, our analysis provides additional validity and nuance to the previous findings, allowing us to discuss the impact of different policy approaches to regulating cannabis supply. We summarize our insights below.

Outcomes of cannabis regulation – commonalities across jurisdictions

An overarching benefit of cannabis legalization in all jurisdictions included in this study (the Netherlands, Spain, U.S. states, Uruguay, and Canada) was a decrease in cannabis-related arrests. A reduction in cannabis-related crime may yield more efficiency and resource allocation in law enforcement agencies and, importantly, promote social justice for individuals and communities affected by cannabis-related criminalization (Adinoff & Reiman, 2019). This was primarily measured as the rate of cannabis offences on all drug offences and ranged as low as 22 % in Uruguay or 24 % in Canada. In jurisdictions where cannabis remained de jure illegal, the proportion of cannabis offences on all drug offences was higher (41 % in The Netherlands and 80 % in Spain), suggesting that more benefits in social outcomes are achieved when cannabis is fully legalized.

Across all jurisdictions, there was a clear indication of an increased prevalence of recent cannabis use in the adult population in relation to the provision of regulated cannabis. The increase in cannabis use among adults can be explained by several factors, including the potential reduction of any under-reporting due to reduced stigma and criminalization, although the size of such bias has not been measured (Hammond et al., 2020). Increase in cannabis use rates may be largely reflective of experimental and non- harmful use (Sznitman et al., 2015); however, concerns remain that any cannabis use may increase the risk of developing a cannabis use disorder in up to one-fifth of all new cannabis users (Leung et al., 2020), with greater frequency of use increasing the risk (Robinson et al., 2022). The evidence on increased problematic cannabis use was mixed in our study with data often lacking, and it has only been shown in the U.S. to date (Cerdá et al., 2020, Weinberger et al., 2022). There are uncertainties regarding whether cannabis use may reduce other substance use or harms (Smart & Pacula, 2019; Pacula et al., 2022), making it premature to conclude that potential harms from cannabis use offset those associated with other drug use.

At the same time, there was not a clear indication of a rise in cannabis use among youth/adolescents, as only two out of five U.S. studies (Cerdá et al., 2017; Gunadi et al., 2022) and one out of three Canadian studies (Gunadi et al., 2022) found an increase. This suggests that young people can't readily access these regulated markets with cannabis, as intended by most cannabis regulation policies (Watson & Erickson, 2019), with the hope that cannabis experimentation will be delayed until adulthood, thereby reducing cannabis-related harm (Watson & Erickson, 2019). However, young people who use cannabis may continue to experience the negative social impacts of cannabis prohibition; concerning, one study also found an increase in youth cannabis allegations following cannabis legalization (Firth et al., 2020).

Across all five jurisdictions, there was some evidence regarding cannabis-related presentations in emergency departments (EDs) or hospitalizations increasing following the introduction of regulated cannabis supply (or being relatively greater than in a comparable jurisdiction without such supply). Increased cannabis-related ED and hospital presentations incur costs to the health-care systems, diminish the well-being of individuals who use cannabis and their families, or result in decreased productivity (Shanahan & Ritter, 2014). The causes for increased presentations are multifaceted. In addition to potentially corresponding with an increase in cannabis use, it is also important to note other contributing factors, such as increased help-seeking for cannabis-related health issues when its possession and use are not criminalised, or increase in screening for cannabis use following its legalization (Rehm & Manthey, 2020).

Differences between jurisdictions – potential outcomes of different regulations?

There were some differences in the outcomes of cannabis supply policies across the jurisdictions in this study. Firstly, cannabis supply models in the U.S. states and Canada have clearly yielded tax benefits,

driven by legislation and profit-orientated behavior of cannabis entrepreneurs. Tax revenues weren't planned or observed in the Netherlands, Spain, or Uruguay. Moreover, there are rulings in place by the European Court that prevent collecting VAT from the sales of cannabis products considering they remain *de jure* illegal (this applies to Spain and the Netherlands as well as the rest of the European Union).

The orientation toward increased tax revenue may counteract public health objectives. In particular, the U.S. was the only jurisdiction with consistent evidence of increased cannabis use disorder following its legalization (Athanasios et al., 2022), increased hospital admissions related to broader adverse events beyond cannabis use itself (Athanasios et al., 2022; Masonbrink et al., 2021; Wang et al., 2022; Shi & Liang, 2020), and an increase in cannabis-related traffic accidents (Kamer et al., 2020; Lee et al., 2018; Windle et al., 2021; Woo, 2019).

In Canada where entrepreneurial behaviours have been subjected to restrictions (e.g., strict regulation of product packaging and advertising), two papers suggested an increase in cannabis use among adults (Rotermann, 2021) and adolescents (Fischer et al., 2021) at the time of our literature search. However, three other papers did not find an increase in cannabis use among adults (Rotermann, 2021), adolescents (Zuckermann et al., 2021), or in intensive cannabis use (Fischer et al., 2021). In Canada, studies on cannabis-related ED presentations, hospitalizations and traffic accidents showed both increases (Kim et al., 2022; Callaghan et al., 2023c; Myran et al., 2022a; Myran et al., 2023a, 2023b; Yeung et al., 2021; Yeung et al., 2020) and no or limited impact post-legalization (Auger et al., 2021; Baraniecki et al., 2021; Ball et al., 2021; Anderson et al., 2024; Myran et al., 2023a; Myran et al., 2022b). As the Canadian model of cannabis supply regulation continues to be evaluated, clearer answers may emerge regarding whether an inverse relationship exists between the higher level of market restrictions there and the lesser cannabis-related harm.

Trade-offs, indexes, and values

If all objectives/indicators were aggregated into a total score, the Dutch and the Canadian model of cannabis legalization might offer the best performance, given that studies showing no outcomes or benefits outnumbered those showing potential harms in these jurisdictions. There is a debate over the development of single-score drug policy indexes, particularly in relation to assessing cannabis legalization policies (Barata et al., 2022; Thornton, 2021); our analysis may inform further research in this area by pointing to the level and the direction of evidence across relevant jurisdictions and outcomes

It has been argued that there may be trade-offs in cannabis regulation models and each could impact the outcomes indicators differently (Queirolo, 2020a). There may be trade-offs between the harms and benefits, as previously outlined by a "curve" model with the 'golden spot' in the middle representing the overall highest benefits and lowest harms of a given policy (Transform Drug Policy Foundation 2013; Alice Rap 2014; Anderson et al., 2017; Mravčík et al., 2019). Perhaps it is not possible to open a new, legal market, without rising consumer interest (at least in the short term), or to tightly control the market while making it attractive enough for existing consumers. Further studies may assess whether public-health benefits from participation in the legal market along with social safety and economic benefits, may outweigh potential harms (Shanahan & Ritter, 2014; Brown et al., 2023; Hall, 2020b).

Inherent to such work may be exploring how different policy objectives are valued among various stakeholders. For instance, this may help determine whether substantial tax revenue can be considered adequate compensation for any increased (non-fatal) health emergencies related to cannabis post-legalization. Recent studies among stakeholders in drug policy have revealed that public health outcomes were seen as more important than criminal aspects, and much higher than tax

revenue (Wilkins et al., 2022; Rogeberg et al., 2018), though perceptions among a broader range of stakeholders may differ. Jurisdictions considering *lex lata* cannabis legalization models (i.e., those claiming compliance with international treaties as they are) may need to prioritise public health and harm reduction as the primary objectives of legalization efforts in order to comply with the international law (Jelsma, 2022; Jeanroy et al., 2022).

A mix-and-match proposal

Policy makers may wonder whether an ideal cannabis policy model exists, one that incorporates elements from different cannabis supply regulation models to achieve benefits across all domains (or that offers the best ration of benefits and harms).

In the Czech Republic, a proposal for cannabis legalization, developed by a group of researchers and experts (some of whom co-authored this paper) suggested including licencing practices from U.S. states to ensure an attractive, yet safe product can compete with the illegal market (Gettman & Kennedy, 2014), balanced with a ban on advertising similar to Canadian and Uruguayan models. The Dutch experience of authorising cannabis consumption on premises (known as "coffee shops") was used in proposing cannabis consumption venues that do not serve alcohol.

Cannabis social clubs, like those in Spain, were also proposed alongside the commercial market to offer opportunities for communal cannabis cultivation and consumption. The proposal included individual consumer accounts similar to the Uruguayan model, but with the addition of targeted harm reduction and treatment interventions for individuals who increase their use (Obradors-Pineda et al., 2021). To date, this model of cannabis supply regulation has not been supported through a political process in the Czech Republic and whether this proposal will be accepted in its full, in part, or gets rejected, remains uncertain.

Limitations

Limitations to study design

There were clear differences between jurisdictions in this study regarding the level of available evidence on cannabis-legalization outcomes. The highest level of harms from regulated cannabis supply was observed in the U.S. states (as a group) which, coincidentally, had the highest quality of research design – quasi-experimental (longitudinal and comparative) studies were available for majority of the outcomes there.

Only one study with quasi-experimental design was found for each Uruguay, Netherlands, Spain, and none for Canada – the remaining studies in these jurisdictions used a study design which is less suited to indicate causality between a policy and an outcome. With this in mind, findings from the remaining jurisdictions should be interpreted with caution, as the observed benefits or harms may not be associated with the respective cannabis supply models in these jurisdictions but, rather, be a result of pre-existing trends (e.g. in longitudinal studies from Uruguay or Canada) or socio-cultural differences (e.g. for comparative data from The Netherlands, Spain, and the neighbouring countries).

The lack of quasi-experimental design may be particularly apparent in the Netherlands and in Spain with the absence of pre- / post- longitudinal studies. Cannabis supply models in the Netherlands and in Spain have gradually evolved over time and in a grassroots fashion, without a strong emphasis on pre-planned regulations with built-in evaluation. While comparisons with other countries have been made on some key indicators available through EUDA, it should be noted that cultural and procedural differences between European countries may be greater than between individual U.S. states. Nevertheless, including these two countries in the analysis is valuable because their cannabis supply

models have been long-standing, and any immediate trends have likely already settled.

Limitations to timeframes

Timeframes for studies included in this analysis weren't restricted, which could result in including recent and historical data alike. In addition, the (somewhat optimistic) Canadian evidence-base was generated during a relatively short duration of cannabis legalization. As Mantey et al. aptly stated, assessing the impact of Canadian legalization should give greater weight to studies conducted later in time that control for pre-existing trends and capture policy differences across jurisdictions (Mantey et al., 2023), as well as for increased access to cannabis over time across Canadian provinces (Myran et al., 2019; Myran et al., 2022c).

Limitations to policy differences between U.S. states

In the U.S., the relative cultural uniformity and nationwide datasets have allowed for extensive comparisons between states that did and did not legalize cannabis supply and, simultaneously, capturing changes before and after cannabis supply regulation. However, this approach may overlook the nuances of state-level cannabis supply models. For instance, a large body of research highlighted issues with cannabis edibles being a major cause of healthcare utilisation among children and adults (Conerney et al., 2024; Wang et al., 2020). This issue was driven by the lack of labelling and regulation of cannabis edibles during the early stages of cannabis legalization in Colorado. The state made amendments to their regulations, which regulators in other U.S. states and overseas have since learnt from (Lake et al., 2019). As another example, a recent literature review (O'Grady et al., 2024) identified studies showing an increase in cannabis use among adolescents and young adults in California, which has a less regulated cannabis market (Paschall et al., 2021; Paschall et al., 2022), while studies from Washington state, which has stricter regulations in place, showed either decrease in adolescent use of cannabis following legalization (Ta, 2019; Dilley et al., 2019) or no change (Estoup et al., 2016; Mason et al., 2016; Blevins et al., 2018). Many regulatory nuances exist across U.S. states with regulated cannabis supply, such as number of issued licences, volume of cannabis per licence, or licence fees (Windle & Wilson, 2022), and these differences may influence outcomes (Pacula et al., 2013; Blanchette et al., 2022). Further quasi-experimental studies assessing the outcomes of regulated cannabis supply should pay closer attention to such nuances, as demonstrated by a recent study showing a relationship between cannabis policy restrictiveness and rates of cannabis use across U.S. states (Pessar et al., 2025).

Limitations to reporting on common outcomes

Finally, the outcomes of cannabis supply regulation identified in this review may not reflect the objectives of cannabis supply regulations in their respective jurisdictions. In Canada, the stated objectives of cannabis supply regulation closely align with the outcomes assessed in this study, namely "to keep cannabis out of the hands of youth", "to keep profits out of the pockets of criminals", and "to protect public health and safety by allowing adults access to legal cannabis" (Seddon, 2020). However, the objectives in other jurisdictions vary. For example, one aim of the Dutch cannabis policy has been to prevent marginalisation, stigmatisation, and criminalisation of people who use cannabis, as well as to prevent initiation of other illicit drug use. In Uruguay, the rationale was to reduce violence related to drug trafficking, or to improve public health through education and prevention campaigns (Queirolo et al., 2019). In the U.S. states, cannabis supply regulation was enacted through state-level ballot initiatives (Seddon, 2020). For instance in Colorado, the objectives of Amendment 64 which introduced cannabis legalization include tax revenue, health and safety, individual freedom, or efficiency of law enforcement resources. Only some of these domains have been identified in our study; the reasons for this may be complexities in measuring outcomes like stigmatisation, law enforcement

efficiency, or transition into other drug use (Boury et al., 2022), or simply lack of interest in measuring these outcomes internationally. It is a limitation to our analysis that policy makers looking into regulating cannabis supply may prioritise different outcomes than those we have been able to assess in this review.

Conclusions

Our analysis has highlighted common outcomes across all jurisdictions with legal adult-use cannabis supply to date: a decrease in cannabis-related arrests, an increase in adult, but not adolescent, cannabis use, and an increase in healthcare utilisation (but not traffic-related). These findings have been observed across both long-standing as well as relatively new cannabis supply regimes, and across different models of cannabis supply. However, differences in study design, timeframe, policy nuances, or availability of research on specific outcomes potentially limit our findings.

When comparing the U.S. states which legalized adult use of cannabis with Canada (or other jurisdictions), more adverse health-related outcomes were observed in the U.S. However, the Canadian model which (unlike U.S. states) banned advertising is a relatively recent one and some of the adverse outcomes might emerge in the future. Additionally, neither Canada, nor the other jurisdictions in this study adopted quasi-experimental designs to the same extent that as research in the U.S. has, meaning that these outcomes may not have been sufficiently examined elsewhere. Based on the evidence presented in our study, it seems though plausible that there may be trade-offs between social and health-related outcomes, depending on the choice of a cannabis regulation model.

Future jurisdictions considering a regulation of cannabis supply may attempt to mix and match specific elements from the existing models. Whether any particular policy mix may yield favourable outcomes across all indicators remains uncertain. More research is needed to understand into which features of cannabis regulation influence the outcomes.

CRedit authorship contribution statement

Vendula Belackova: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Benjamin Petruzelka:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Jakub Cihak:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Jana Michailidu:** Writing – review & editing, Conceptualization. **Viktor Mravcik:** Writing – review & editing, Conceptualization.

Declaration of competing interest

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