Cannabis Legalization and Cognitive Skills of Canadians
A Difference-in-Differences Analysis

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Abstract

The legalization of recreational cannabis in Canada in 2018 marked one of the most pivotal public policy shifts of the past decade, drawing attention to its broader social and cognitive effects. This study examines how adult cognitive skills in Canada evolved over the decade surrounding the legalization of recreational cannabis in 2018. Using nationally representative microdata from the 2012 and 2022 waves of the Programme for the International Assessment of Adult Competencies (PIAAC), the analysis compares changes in literacy, numeracy, and problem-solving scores in Canada with those observed in Germany and Ireland, two advanced economies that did not implement similar legislative reforms during the same period. The study applies a difference-in-differences framework and controls for demographic and educational factors, focusing on population-level patterns rather than individual behavioural responses. Across all three countries, average cognitive scores increased between 2012 and 2022, but the magnitude of improvement differed. The estimates indicate that gains in Canada were smaller than those observed in the pooled comparison group, although the differences were modest and consistent with descriptive evidence. These results should be interpreted as relative changes in national trends rather than as evidence of a direct effect of legalization. The findings contribute to a limited body of research linking large-scale policy environments to standardized skill outcomes among adults and highlight the importance of considering demographic change, educational systems, and broader social developments when interpreting shifts in national performance. Moreover, this study adds to the literature that looks at how wider policy settings relate to adult skill outcomes. They also serve as a reminder that demographic aging, differences in education systems, and other social or economic developments all shape how cognitive scores move over time.

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1 Introduction

Over the last decade, cannabis policy has undergone rapid changes across a number of high–income countries. Several jurisdictions have moved away from prohibition toward more regulated models, reflecting changes in public attitudes, enforcement priorities, and health–based policy frameworks. Canada was the first G7 country to legalize recreational cannabis nationwide in October 2018, marking a notable policy transition that has drawn considerable research attention. Legalization not only aimed to reduce reliance on the illicit market, improve product safety, and restrict youth access, but it also created interest in how broader social and behavioural outcomes may evolve alongside the reform. Rather than focusing solely on substance use or healthcare utilization, recent work has begun to explore whether legalization may coincide with changes in outcomes that are indirectly connected to everyday functioning, such as educational participation, labour–market engagement, and cognitive performance.

Cannabis interacts with the endocannabinoid system, which plays a critical role in attention, memory, and executive functioning. While medical and psychological studies have explored short-term effects on individuals, the long-term consequences at the population level remain less understood. For instance, Vacaflor et al. (2020) found that although cognitive effects among older adults tend to be modest, prolonged exposure to cannabis can lead to mild deficits in memory and attention, particularly among frequent users. Cognitive skills, most commonly measured through literacy, numeracy, and problem–solving assessments, play a central role in modern economies. They influence employability, productivity, and adaptability in technology–intensive environments.

Although clinical and experimental studies have examined short–term cognitive effects of cannabis at the individual level, much less is known about how cognitive outcomes evolve at the population level in countries that undergo major policy reforms. Existing evidence is mixed. Some studies document small performance differences among heavy or long-term users, while others report that observed gaps are largely explained by socioeconomic background, baseline ability, or associated behaviours such as sleep, stress, or alcohol use. Most importantly, the majority of prior work relies on small samples, clinical settings, or adolescent populations, limiting the ability to generalize findings to entire national populations.

Before legalization, cannabis use in Canada was already common, especially among young adults. The legalization reform was framed as a public health measure rather than a moral or punitive one, aiming to protect consumers and regulate supply. Following legalization, cannabis became available through licensed retailers and online platforms, with each province determining its own distribution model. Germany and Ireland, by contrast, maintained a restrictive legal framework during the period studied, allowing for limited medical use but prohibiting recreational sales.

In the years following legalization, both surveys and administrative data show substantial changes in consumption patterns across Canada. The 2022 Canadian Cannabis Survey (CCS) reported that 27 percent of Canadians aged 16 and older had used cannabis in the previous year, underscoring the normalization of cannabis use and the expansion of regulated access. The highest usage was among young adults. Nearly half of those aged 20 to 24 reported using cannabis in the previous year, compared with about one in four adults aged 25 and older. Educational attainment also appeared to moderate usage, where, 33 percent of individuals with a high school education or less reported use, compared to 19 percent among university graduates. Native-born Canadians reported nearly twice the rate of use as immigrants, and daily or near-daily use became more common. Traditional smoking remained the dominant method, though alternative modes such as edibles and vaping gained popularity. These patterns reveal both diversification in consumption and growing social acceptance.

Figure 1 illustrates the increase in cannabis use among Canadian adults by age and gender between 2018 and 2022. The figure shows that consumption rose steadily across all demographic groups after legalization, with the sharpest increases among young adults. Among men aged 16 to 24, usage nearly doubled from around 22 percent in 2018 to over 40 percent in 2022, while women in the same age range rose from about 17 to 36 percent. Middle-aged adults also increased their participation, and even older groups exhibited gradual growth, often for therapeutic reasons. These trends confirm that cannabis use became more normalized across society and that gender differences narrowed as legalization took hold. [1]

The potential connection between cannabis use and cognitive performance is well documented in clinical and experimental research. Acute exposure can impair attention and memory, while long-term or heavy use may lead to more persistent deficits. Hall and Lynskey (2020) argue that early and sustained use, especially during adolescence or early adulthood, can have lasting cognitive consequences even after periods of abstinence. Yet, how these individual-level effects translate into aggregate outcomes at the national level remains unclear. Understanding this relationship is increasingly relevant as cognitive skills play a central role in modern labor markets, influencing employability, productivity, and economic growth.

Public discussions of legalization often focus on justice reform, taxation, and health regulation, leaving the cognitive and behavioral dimensions largely unexplored. Most existing studies on legalization have concentrated on mental health, consumption prevalence, or youth outcomes, but few have examined whether these behavioral changes are reflected in national measures of cognitive ability. This study addresses that gap by linking policy changes to standardized skill

1. Data are drawn from the Canadian Cannabis Survey (2022) and earlier national sources, including CTADS (2013-2015) and NCS (2018), published by Health Canada. All figures report past-year cannabis use among individuals aged 16 and older.

assessments, providing a bridge between public health research and economic policy evaluation.

A separate challenge relates to measurement. Much of the existing research relies on self-reported ability or small-scale psychological tasks, which may not capture the kinds of literacy, numeracy, and problem-solving skills that adults use in everyday life or that matter in the labour market. In contrast, large standardized assessments such as the Programme for the International Assessment of Adult Competencies (PIAAC) offer a broader picture. PIAAC measures skills that are directly linked to work and economic participation and is collected using nationally representative samples. Because it is administered in multiple countries and repeated at different points in time, it allows for meaningful comparisons of how skill distributions change across populations. This study uses the 2012 and 2022 PIAAC waves to examine whether cognitive outcomes in Canada developed differently from those in Germany and Ireland over the decade that included Canada's legalization of recreational cannabis.

The goal of this paper is not to identify the direct cognitive effects of cannabis use, nor to establish a causal relationship between legalization and national skill levels. Instead, the analysis examines whether population–level trends in cognitive performance in Canada between 2012 and 2022 differ from those observed in comparable countries that did not undergo the same reform during this period. Germany and Ireland provide useful reference points: both are advanced economies with comparable demographic structures and education systems, but neither legalized recreational cannabis before 2022. Using these countries as comparison groups allows the analysis to situate changes in Canada within a broader international context rather than attributing them to a single event. [2]

A preview of the results helps clarify the scope of the findings. Across all three countries, cognitive scores increased between 2012 and 2022, consistent with improvements observed in many high-income populations over time. However, the increase in Canada was smaller relative to the pooled comparison group of Germany and Ireland. In percentage terms, average cognitive scores rose by roughly 2% in Canada, compared with gains of approximately 4-6% in Germany, while Ireland remained close to Canada throughout the decade. The regression estimates do not isolate mechanisms behind the observed patterns and cannot rule out the influence of other country-specific developments that occurred alongside legalization.

It is important to recognise that cannabis policy was not the only institutional change taking place during this period. Canada experienced shifts in postsecondary participation, changes in occupational structure, and rapid digital adoption, particularly during and after the COVID–19 pandemic. Germany expanded its vocational and adult education system and implemented labour market reforms unrelated to cannabis policy. Ireland experienced substantial increases in educa-

2. Germany legalized recreational cannabis in 2023, after the period examined in this study. Ireland did not implement legalization during this time.

tional attainment and population growth, shaped by migration and economic expansion. These developments could plausibly contribute to changes in national skill distributions, independent of cannabis legislation.

The contribution of this study is threefold. First, it is one of the few cross-country analyses to explore cognitive outcomes around cannabis legalization using harmonized and nationally representative microdata. Second, rather than relying on self-reported measures or focusing only on adolescents, it uses standardized skill assessments that are closely connected to real-world labour-market performance. Third, it provides both descriptive patterns and regression-based comparisons of how cognitive trends in Canada shifted relative to similar countries over a ten-year period, without treating legalization as the sole driver of those changes. By situating cannabis policy alongside broader forces such as demographic shifts, educational differences, and economic conditions, the study emphasizes that national outcomes can evolve gradually for many reasons, and not because of any single change on its own.

While many economic and social conditions were changing over the period studied, cannabis legalization stands out as a major nationwide policy shift in Canada that coincided with a clear rise in adult cannabis use. Comparing Canada with Germany and Ireland helps put these changes into perspective, since neither country introduced a similar reform during this time. Although this analysis does not claim that legalization alone explains the observed differences in cognitive outcomes, the timing and scale of the policy change, together with the documented increase in post-2018 cannabis consumption, suggest that legalization may have played a role in shaping the divergent trends across countries.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature; Section 3 describes the data sources, variable construction, and descriptive statistics; Section 4 outlines the empirical methodology; Section 5 presents the regression results; Section 6 discusses the findings and their policy implications; and Section 7 concludes.

2 Literature Review

The legalization of recreational cannabis in Canada in 2018 has encouraged researchers across public health, economics, psychology, and social policy to reassess how cannabis use fits into everyday life. Rather than focusing solely on clinical or medical outcomes, recent work has shifted toward examining broader behavioural patterns and social responses to legalization. Much of this literature suggests that cannabis has become more accessible and socially normalized in Canada, but that these changes unfolded gradually rather than abruptly.

A growing number of studies document changes in use and access following legalization.

Doggett et al. (2025) compare young adults in Canada and the United States using survey data collected before and after legalization. Their study focuses on emerging adults aged 18-25 and shows that Canadian respondents reported higher past-year use, greater perceived access, and more frequent exposure to cannabis in social settings after legalization. The authors emphasize that these changes did not occur immediately in 2018 but accumulated over several years, suggesting adaptation rather than sudden behavioural shifts. In a separate national survey analysis, Hammond et al. (2020) track patterns in cannabis use among adults using repeated cross-sectional data from the International Cannabis Policy Study. They report increases in overall consumption, a broader range of product types, and a clear transition from illegal to legal purchasing sources. Their findings highlight that legalization altered the market structure and consumer behaviour at the population level, even though the timing and magnitude of changes differed across demographic groups.

Broader population evidence reinforces this gradual adjustment. Using multiple national datasets, Bahji et al. (2022) examine adult cannabis use over time and find continued growth in consumption among individuals aged 25-54, even several years after legalization. Their results contrast with the trajectory of alcohol and tobacco, where usage typically stabilizes following major regulatory reforms. Meanwhile, Rubin-Kahana et al. (2022) analyze youth participation rates and find little change in cannabis use among teenagers, suggesting that age restrictions and regulatory safeguards may have been effective. Together, these studies show that legalization primarily influenced adult rather than adolescent behaviour, and that increased access did not translate into uniform increases across all groups. However, the existing evidence does not clarify whether these behavioural shifts have implications for cognitive skills or long-term human capital.

The relationship between cannabis and cognition has been studied for decades, but findings remain mixed. Early experimental research such as Grant et al. (2003) relies on controlled laboratory settings to measure short-term changes in attention, memory, and reaction time following acute cannabis exposure. These studies consistently find temporary impairments that fade after a period of non-use. More recent reviews, including Broyd et al. (2016), summarize evidence from clinical and neuropsychological experiments and conclude that acute cognitive effects are generally small and short-lived. However, these designs are limited in duration and rely on selective samples, making it difficult to infer broader or lasting population-level effects.

Long-term outcomes are even less settled. In a large meta-analysis, Scott et al. (2018) compare cognitive test performance among chronic cannabis users and non-users across multiple studies. Although they find small differences in measures such as learning and memory, these differences shrink considerably once socioeconomic background, alcohol use, and education are taken into account. The authors argue that cannabis use is often intertwined with other disadvantage-related factors, making it difficult to isolate cannabis-specific effects. The well-known Dunedin cohort analysis by Meier et al. (2012) reported declines in IQ among individuals who used cannabis heavily from adolescence into adulthood. However, Mokrysz et al. (2016) re-examined the same issue and argued that much of the observed decline could be explained by pre-existing differences in family environment and early-life cognitive ability. These contrasting findings illustrate how results depend heavily on research design, adjustment for confounders, and definitions of heavy or persistent use.

Neuroimaging evidence adds another layer of uncertainty. Reviewing structural brain studies, Lorenzetti, Hoch, and Hall (2020) find that frequent adolescent users exhibit differences in brain regions associated with memory and executive function. However, many of these differences appear to be reversible after sustained periods of abstinence. Taken together, the clinical and psychological literature suggests that while cannabis may influence certain cognitive processes under specific conditions, the long-term population-level effects remain unclear and highly context dependent.

Several studies suggest that cannabis may influence cognition indirectly rather than through direct neurobiological effects. Schwarz and Maschmann (2022) document small increases in anxiety and depressive symptoms in the years following legalization, particularly among frequent users. They argue that mental health, sleep quality, and stress may serve as channels linking cannabis use to cognitive functioning. Similarly, George, Hill, and Vaccarino (2018) highlight risks for individuals with pre-existing psychological vulnerabilities and emphasize variation across users rather than uniform effects. These findings reinforce the idea that cognitive performance is shaped by broader behavioural and emotional factors, not cannabis exposure alone.

Age-specific patterns further complicate interpretation. Vacaflor et al. (2020) focus on adults aged 55 and over and find mixed cognitive outcomes, with some individuals reporting mild memory concerns and others showing no change. Their results suggest that older adults may experience cannabis differently, often using it for therapeutic purposes rather than recreation. Wadsworth et al. (2025) document increased cannabis use among older Canadians after legalization, emphasizing that motives and expected outcomes differ sharply across age groups. These studies imply that national averages may conceal important cohort differences, and that policy effects, if any, may not be uniform across the population.

Economic research offers additional perspectives by linking cannabis access to education and labour-market outcomes. Using variation in Dutch cannabis policy, Marie and Zölitz (2017) show that reduced access to cannabis improved student performance and school completion rates, suggesting that substance availability can influence human capital accumulation. In the United States, Weinberger et al. (2022) find that legalization widened consumption gaps across income groups, indicating that social and economic context shapes behavioural responses to policy changes. Although these studies do not examine cognition directly, they highlight the potential for cannabis policy to interact with economic opportunity and skill development.

Despite extensive research on cannabis, relatively few studies examine cognitive outcomes using large, nationally representative data. Many rely on adolescent samples, self-reported ability, or short-term clinical measures. Cross-country analyses are especially rare, and most existing work lacks pre-policy baseline data or an external comparison group. These limitations make it difficult to distinguish whether observed changes reflect legalization or broader social and demographic trends.

This study contributes to this gap by using harmonized PIAAC microdata from Canada, Germany, and Ireland to compare how cognitive outcomes evolved over time rather than to estimate the direct effects of cannabis use. By combining insights from public health, psychology, and economics, the analysis treats legalization as part of a wider set of social changes rather than an isolated event. The findings are best interpreted as differences in relative trends, acknowledging that multiple forces, including education systems, demographic shifts, and labour-market conditions, shape national cognitive outcomes over time.

3 Data

This study uses data from the Programme for the International Assessment of Adult Competencies (PIAAC), conducted by the Organisation for Economic Co-operation and Development (OECD). PIAAC is a large-scale international survey designed to evaluate adult skills in literacy, numeracy, and problem solving in technology-rich environments. The dataset provides detailed information on educational attainment, demographic characteristics, and labor market participation, which allows for meaningful cross-country comparisons of skill outcomes. It also uses data from the Canadian Cannabis Survey (CCS) to provide contextual evidence on how cannabis use patterns evolved in Canada over roughly the same period. The CCS does not enter the regressions directly; instead, it helps interpret the aggregate trends observed in the PIAAC data by documenting changes in consumption behaviour around the legalization of recreational cannabis.

The structure of the PIAAC waves aligns closely with the policy environment relevant to this study. Two survey cycles are used in this analysis: 2012 (Cycle 1) and 2022 (Cycle 2). These years capture the period before and after Canada's legalization of recreational cannabis in 2018, with Germany and Ireland serving as the comparison countries that did not implement a similar reform during the same period, making them useful reference countries for comparing how cognitive outcomes evolved over time in settings without the same policy shift. Restricting the analysis to these two time points allows for a clear Difference-in-Differences framework centered around the policy change. The objective of the analysis is therefore not to study individual cannabis use, but to examine whether population level trends in cognitive skills in Canada differed from those observed in similar high-income countries over the same decade.

Following the existing literature, this study uses the plausible-value means in each domain and constructs an average cognitive score as the simple mean of the three components. The analysis is restricted to native-born adults aged 18–65 in each country, and all descriptive statistics and regressions are weighted using the person weights (SPFWT0) supplied by PIAAC to recover nationally representative estimates.

Tables 2, 3, and 4 summarize the characteristics of native-born adults in Canada, Germany, and Ireland in 2012 and 2022. In the summary statistics of Canada (Table 2), the three skill areas: literacy, numeracy, and problem solving are fairly similar in 2012, with average scores of 270.3, 259.6, and 278.6 points, respectively. Over the following decade, these scores change slightly. Literacy improves by about 7.6 points (roughly 2.8%), and numeracy increases by around 14.6 points (about 5.6%), while problem-solving shows a small decline of roughly 14.9 points (–5.3%). Because these movements offset one another, the overall average cognitive score rises only modestly, from 266.4 to 272.0 points, an increase of about 2.1%. Educational attainment follows a clearer upward trend. The average years of schooling among native-born Canadians increases from 12.7 to 13.4 years (around 5%), which is consistent with gradual improvements in education levels over time rather than any abrupt shift.

Germany and Ireland display somewhat different patterns relative to Canada. In 2012, German adults already score slightly higher than Canadians in all three domains (Table 3). German literacy and numeracy scores exceed Canadian scores by around 1–6% (273.6 vs. 270.3 in literacy and 275.5 vs. 259.6 in numeracy), and the average cognitive score is about 6% higher (283.1 vs. 266.4). By 2022, these gaps have widened. German numeracy and average cognitive scores are around 6% and 4% higher than the corresponding Canadian scores, and German adults complete roughly one additional year of schooling on average. In percentage terms, Germany's average years of schooling are about 9% higher than Canada's in 2012 and about 8% higher in 2022. This suggests that part of the cross–country difference in skill distributions is likely related to differences in educational attainment rather than to any single policy change.

Ireland's position relative to Canada is somewhat different (Table 4). In 2012, mean Irish cognitive scores are very close to the Canadian levels: literacy, numeracy, and problem–solving scores differ from Canada's by less than one percentage point in either direction, and the average score is only about 1% lower than in Canada. However, Irish adults have substantially more schooling, with average years of education around 15% higher than in Canada. By 2022, Irish cognitive scores remain close to the Canadian distribution, but the pattern reverses slightly: Ireland's average score is about 4–5% lower than Canada's, while average years of schooling are still roughly 13% higher. Taken together, these comparisons indicate that Canada sits between Germany and Ireland in terms of formal education, but its cognitive scores are closer to Ireland's than to Germany's throughout the period.

The categorical variables in Tables 2, 3, and 4 show that the basic demographic composition of the three samples is broadly similar. Female shares are almost identical across countries and over time, hovering around 0.52–0.54, so gender composition is unlikely to drive large differences in skill distributions. The age distributions also evolve in comparable ways. In all three countries, the share of younger adults (18–34) tends to fall between 2012 and 2022, while the proportion of older adults (55–65) rises. For example, in Canada the share of 55–65 year olds increases from about 24% to 33%; in Germany the corresponding share grows from 18% to 23%; and in Ireland it rises from 21% to 26%. These shifts reflect population aging and should be kept in mind when interpreting changes in average cognitive scores over time, since older cohorts typically perform somewhat less well on these tests than younger adults.

The rows on education categories summarize the distribution of schooling in each country. Canada has a relatively large share of individuals in the ”high” and ”very high” schooling groups (11–18 years) and smaller shares at the extremes. Germany exhibits a broadly similar pattern, but with slightly more mass in the medium and high categories. Ireland, by contrast, has a particularly large proportion of adults in the ”very high” schooling group, especially in 2012, where more than half of the sample reports 15–18 years of schooling. These descriptive patterns underline that cross–country differences in the level and distribution of education are sizeable even before considering cannabis policy differences.

To assess how comparable Canada is to the pooled control group of Germany and Ireland at baseline, Table 5 reports Welch unequal variance t–tests for differences in means between native-born Canadians and the combined sample of native-born Germans and Irish in 2012. For literacy, the mean score in the control group is only about 1.1 points higher than in Canada, a difference of less than 0.5% of the Canadian mean, and the associated p–value (0.0838) indicates that this difference is not statistically significant at the 5% level. By contrast, numeracy scores are about 7.1 points higher in the control group (roughly 2.7% of the Canadian mean), and the p–value is effectively zero, indicating a statistically important difference. Problem–solving and average cognitive scores are also higher in Germany and Ireland, by about 3.2 and 3.6 points respectively (around 1–1.5% of the Canadian means), and these differences are again statistically significant. The largest baseline difference appears in years of schooling: adults in Germany and Ireland report, on average, about one additional year of education relative to Canada, which corresponds to an 8% difference and is highly statistically significant.

The lower panel of Table 5 compares demographic structure across Canada and the pooled control group in 2012. Female shares differ only slightly (0.538 in Canada vs. 0.525 in Germany+Ireland), and the Welch p–value of 0.064 suggests that this difference is small both in magnitude and statistical terms. Age–group shares are generally close, but there are some noteworthy contrasts. Canada has a somewhat larger share of younger adults in the 18–24 category and a smaller share of individuals aged 35-44 than the control group. These baseline differences are important because they show that the treated and control populations are similar, but not identical, in their age and education profiles. The regression analysis therefore controls for age groups and cohort indicators, as well as for gender and years of schooling, to account for these observable differences when comparing changes in cognitive scores over time.

These descriptive patterns are not intended to imply any effect of cannabis policy, but instead establish the baseline similarities and differences across countries prior to the regression analysis. They provide the context needed to assess whether changes in cognitive outcomes in Canada after 2018 move in line with, or differently from, countries that did not experience the same policy shift.

Overall, the descriptive evidence paints a clear picture of the data environment used in this empirical analysis. Cognitive scores are reasonably high and broadly comparable across Canada, Germany, and Ireland, with Germany typically scoring a bit above the other two countries and Ireland tracking Canada more closely. At the same time, Germany and especially Ireland have higher average schooling, and all three countries experience population aging between 2012 and 2022. Taken together, these patterns suggest that changes in cognitive scores over time are likely shaped by a combination of factors including differences in education systems, shifting population structures, and broader country-level developments, rather than any single event on its own. With this in mind, the difference-in-differences approach used in the following section focuses on comparing how trends evolved across countries, providing a way to assess relative changes against a background of gradual and varied developments.

Before conducting the regression analysis, the datasets were cleaned and harmonized to ensure consistency across survey cycles. Observations with missing cognitive scores or key demographic information were removed, and implausible values were excluded. After combining the countries into a pooled dataset and applying population weights, the final analytical sample included roughly 27,000 individuals. This cleaned and weighted sample provides a robust foundation for examining cross-country and intertemporal differences in adult cognitive performance. The descriptive results summarized here form the empirical basis for the econometric analysis presented in Section 4.

4 Methodology

This study adopts a difference-in-differences (DID) framework to compare changes in adult cognitive skills in Canada with those observed in Germany and Ireland between 2012 and 2022. Canada is treated as the policy-exposed country, as recreational cannabis was legalized nationally in 2018, while Germany and Ireland did not undergo comparable legislative changes during this period. The aim of the empirical strategy is not to estimate individual behavioural responses, but to examine whether population-level trends in cognitive outcomes evolved differently across countries over time and could this policy change be one of the indirect reasons for it.

The DID specification compares how cognitive outcomes changed in Canada relative to the pooled control group of Germany and Ireland between 2012 and 2022. The regression model is given by:

$$\begin{aligned}\ln(\text{Score}_{it}) &= \alpha + \beta_1\,\text{Canada}_i + \beta_2\,\text{Post}_t + \beta_3\,(\text{Canada}_i \times \text{Post}_t) \\ &\quad + \delta_c + \theta_a + \gamma_1\,\text{Female}_i + \gamma_2\,\text{EducYrs}_i + \varepsilon_{it},\end{aligned} \tag{1}$$

where δ_c denotes cohort fixed effects and θ_a denotes age-group indicators. Detailed descriptions of these terms are provided later in this section. $\ln(\text{Score}_{it})$ denotes the natural logarithm of the cognitive measure for individual i in year t. Four outcomes are examined separately: the average cognitive score and the domain–specific literacy, numeracy, and problem–solving scores. Using the logarithmic transformation allows the coefficients to be interpreted as approximate percentage differences across groups and over time.

The indicator Canada_i equals one for native–born Canadians and zero for native–born respondents in Germany and Ireland. The variable Post_t equals one for observations from 2022 and zero for 2012. The interaction term β_3 is the primary parameter of interest. It captures the difference in how cognitive scores changed in Canada relative to the pooled comparison group over the decade. A negative and statistically significant value would indicate that cognitive performance in Canada rose more slowly than in Germany and Ireland during this period, without implying a direct causal effect of legalization.

Cohort fixed effects (δ_c) account for the fact that individuals observed in 2012 and 2022 belong to different birth cohorts, while age–group indicators (θ_a) adjust for life–cycle differences in cognitive performance. The model also includes controls for gender and years of schooling, recognising that demographic and educational factors are closely related to measured skill levels. Cohorts are defined by birth decade and enter the regression as dummies. To be concise, Table 6 reports them as transitions between adjacent cohorts (25–34 $\rightarrow$ 35–44, etc.). All regressions apply PIAAC sampling weights (SPFWT0) to ensure national representativeness and are estimated with robust standard errors.

The DID approach relies on the idea that, in the absence of policy changes, cognitive outcomes in Canada would have followed a path similar to those in Germany and Ireland. Although this assumption cannot be formally verified with only two survey waves, the baseline similarities documented in the summary statistics and Welch tests provide support for using Germany and Ireland as appropriate comparison countries.

To assess whether Canada and the comparison countries were similar prior to legalization, Welch unequal-variance t-tests are used to compare mean cognitive scores and demographic characteristics in 2012. These tests evaluate whether baseline levels differed across countries, rather than whether outcomes followed parallel trends over time. As such, they do not constitute a formal test of the parallel trends assumption, which cannot be verified with only two survey waves. Instead, the Welch tests provide descriptive evidence that Canada, Germany, and Ireland were broadly comparable in observed characteristics before the policy change, supporting the use of a difference-in-differences framework to examine relative changes over time.

Since, the analysis relies on only two survey waves, it is not possible to directly test whether cognitive outcomes in Canada and the comparison countries were already following parallel trends prior to legalization. As a result, the difference-in-differences estimates rest on the assumption that, in the absence of the policy change, cognitive performance in these countries would have evolved in broadly similar ways. While this assumption cannot be formally verified, the close alignment of baseline cognitive scores and demographic characteristics in 2012 provides some reassurance that Germany and Ireland offer reasonable comparison groups. The results should therefore be interpreted as differences in relative trends rather than as definitive causal effects.

For each specification, standard errors are reported in parentheses and statistical significance at the 1%, 5%, and 10% levels is indicated using the conventional notation. In addition to the coefficient estimates, two model fit statistics are presented: the coefficient of determination (R^2), which reflects the share of variation explained by the model, and the root mean squared error (RMSE), which summarizes the average unexplained variation. Together, these elements provide a transparent framework for comparing how cognitive outcomes evolved across countries over time.

5 Results

Table 6 reports the estimates from the difference-in-differences specifications comparing changes in cognitive outcomes for native-born Canadians with those of native-born respondents in Germany and Ireland between 2012 and 2022. The four dependent variables are the logarithms of literacy, numeracy, problem-solving, and the average of these three scores. All models include cohort and age fixed effects and control for gender and years of schooling, and are estimated using PIAAC sampling weights (SPFWT0). Standard errors are reported in parentheses.

Across all four outcomes, the post-period coefficient is positive and statistically significant, indicating that average cognitive scores were higher in 2022 than in 2012 for adults in all three countries. The magnitude of this increase varies across domains. Problem-solving shows the smallest estimated change (0.344), while numeracy exhibits the largest (0.604), suggesting that gains in quantitative skills over the decade were more pronounced than gains in broader problem-solving abilities. Literacy falls between these two at 0.447, and the average cognitive score rises by 0.510. Across all four skills, the treatment effect is also very similar in magnitude. The negative interaction terms range between -0.054 and -0.061, indicating a consistent pattern of slightly slower improvement in Canada relative to the comparison group across every cognitive domain. It is also noteworthy that, in 2012, literacy scores were essentially the same across Canada, Germany, and Ireland. This reinforces that the countries were well aligned at baseline before comparing how their trends evolved.

These estimates correspond to moderate percentage increases and are consistent with gradual improvements observed in large-scale skill assessments rather than sudden shifts. The positive sign on the Canada indicator across specifications, for example, 0.039 in the model using the average cognitive score, suggests that prior to 2022, Canadians scored slightly higher than respondents in Germany and Ireland, although these differences are small and not central to the interpretation.

The main parameter of interest is β_3, which is the interaction between the Canada indicator and the post-period, which captures how changes in cognitive outcomes in Canada compare to those in the pooled control group. This coefficient is negative in all four models, ranging from –0.054 in numeracy to –0.061 for the average score, and each estimate is statistically significant at conventional levels. These values indicate that although cognitive performance increased between 2012 and 2022 in all three countries, the growth observed in Canada was smaller than in Germany and Ireland. The differences are modest in size and do not imply any abrupt decline in Canadian skills; instead, they reflect slower improvement over time. As the analysis does not attempt to identify mechanisms, the interaction terms should be viewed as descriptive differences in relative trends rather than as evidence of a direct policy effect.

The coefficients on the cohort indicators show a consistent pattern of lower performance among older birth cohorts. Relative to the reference group, transitioning from the 35–44 to the 45–54 cohort is associated with a reduction of approximately 11–12% across outcomes, while the shift from the 45–54 to the 55–65 cohort corresponds to an even larger decline of roughly 16–18%. These results align with well-documented age-related changes in standardized skill assessments and reflect gradual decreases in cognitive performance with advancing age rather than period-specific developments. A similar pattern appears in the age-category indicators: respondents aged 25–34 score between 5–6% lower than those aged 18–24, reinforcing the idea that younger adults tend to perform more strongly on measures of core skills.

An interesting pattern emerges when the treatment effect is compared across age groups. Although cannabis use is most common among younger adults, the estimated differences in cognitive outcomes are larger for older cohorts and smaller for younger ones. This does not necessarily contradict the descriptive evidence on cannabis consumption. The analysis focuses on population-level changes in cognitive performance rather than individual cannabis use, so the estimates capture broader trends that may reflect cumulative or indirect effects over time. In addition, cannabis use among older adults increased noticeably after legalization, often for medical or therapeutic reasons, which may interact differently with cognitive performance than recreational use among younger individuals. Younger cohorts may also benefit from offsetting factors such as higher educational attainment, cognitively demanding work, and more frequent use of digital technologies. Taken together, these factors suggest that the observed age pattern reflects differences in population trends rather than a direct measure of cannabis exposure or harm.

Years of schooling shows a consistent positive association with cognitive outcomes. Across all models, an additional year of education is associated with roughly a 5–6% increase in test performance. This relationship is stable across domains and remains statistically significant, suggesting that educational attainment continues to be an important correlate of skill levels in adulthood. The coefficient on the female indicator is small in magnitude, ranging from –0.004 to –0.048, with statistical significance varying across outcomes. Given their size and inconsistency, these associations are not interpreted further and are included primarily as standard demographic controls.

Model fit is comparable across specifications. The number of observations ranges from 24,708 to 27,025, depending on score availability. The R^2 values fall between 0.183 and 0.209, indicating that the included covariates explain around one-fifth of the variation in test scores. Root mean squared error (RMSE) values lie between 0.145 and 0.202, suggesting a similar level of residual variation across the four domains. These summary measures are consistent with large-scale survey data where individual ability reflects a combination of educational, demographic, and unobserved factors.

Taken together, the results provide a clear picture of how cognitive outcomes evolved during the study period. All three countries experienced increases in literacy, numeracy, and problem-solving scores between 2012 and 2022, reflecting gradual improvements in adult skills over the decade. The negative interaction terms indicate that the rise was smaller in Canada relative to Germany and Ireland. These differences are modest and should be interpreted as relative movements in national skill distributions rather than as evidence of a direct effect of cannabis legalization or any other single factor.

The findings are also consistent with the descriptive evidence presented earlier. Germany entered the period with slightly higher skill levels and experienced somewhat larger gains over time, while Ireland remained closely aligned with Canada across both survey waves. The baseline educational differences, particularly the higher average years of schooling in Germany and Ireland, may contribute to these patterns, along with demographic shifts such as population aging. With only two survey waves available, it is not possible to determine the extent to which these factors explain the observed differences, and the results should therefore be viewed as informative about relative changes rather than as indicators of causal relationships.

Overall, the regression estimates suggest that cognitive scores improved across countries over the decade, but at different rates. Canada's slower improvement places it between Germany and Ireland in terms of relative change, consistent with broader differences in educational attainment, demographic structure, and national developments during this period. Further work would be needed to understand the mechanisms driving these patterns and whether they persist beyond the timeframe examined here.

6 Discussion

The results of this study show that cognitive performance increased between 2012 and 2022 in Canada, Germany, and Ireland, but the size of these gains differed across countries. The Difference-in-Differences estimates indicate that the improvement in Canada was smaller than the change observed in the pooled comparison group over the same period. While the interaction term in Table 6 is negative for all four cognitive measures, the magnitude of the difference is modest. These results align with the descriptive patterns reported earlier, where German scores rose slightly more than Canada's and Irish scores remained closely aligned with Canada's across both survey waves. Taken together, the findings suggest that the evolution of cognitive outcomes over the decade reflects a combination of demographic shifts, differences in educational attainment, and broader country-level developments, rather than a single defining factor.

These results should be interpreted with care. The analysis does not claim that legalization directly caused a decline in cognitive ability. Instead, the evidence is consistent with broader lifestyle and social adjustments following legalization. Easier access and growing social acceptance of cannabis could have influenced daily routines, sleep patterns, or the amount of time devoted to mentally engaging activities such as study, training, or work-related learning. Earlier studies have shown that legalization often leads to higher frequency of use and more diverse consumption methods, particularly among adults in their twenties and thirties. While such behavioral changes are not necessarily harmful for everyone, they may collectively shape how individuals allocate time, focus, and effort, with possible implications for productivity and skill development.

Although many social and economic changes occurred during this period, cannabis legalization remains a particularly relevant policy for interpreting the results. It was a nationwide reform that directly changed access and social acceptance of cannabis, and it coincided with a clear rise in adult use in Canada. Germany and Ireland did not experience similar policy shifts over the same period. The fact that Canada shows consistently slower improvement in cognitive scores after legalization, across all domains, is therefore consistent with legalization being one possible contributor to the observed patterns, even though the analysis does not establish causality.

Placing the findings in context helps clarify their meaning. Ireland experienced changes that remained close to Canada throughout the decade, consistent with the small differences observed in both the descriptive statistics and the regression estimates. These patterns suggest that Canada's slower improvement depicts its relative position between the two comparison countries in terms of schooling and demographic change.

Demographic changes also help explain variation across countries. All three samples show an increase in the share of adults aged 55–65 between 2012 and 2022, and this age group consistently performs below younger adults in the PIAAC assessments. In Canada, the proportion of individuals in this age category increased by nearly ten percentage points, a larger shift than in Germany or Ireland. Even after controlling for age and cohort, such changes may contribute to slower growth in average scores simply because a greater share of the population is in age groups where cognitive performance tends to decline gradually.

Institutional and educational environments offer another potential source of cross-country variation. Canada's trajectory occurred alongside broader social and economic changes, including shifts in postsecondary participation, labor market restructuring, and rapid technological adoption, that could also influence how cognitive skills are developed and measured over time. These differences underscore that the observed patterns likely reflect multiple overlapping factors rather than a single policy transition. An important limitation of the analysis is that, with only two survey waves available, it is not possible to assess whether pre-legalization cognitive trends were already diverging across countries. This reinforces that the estimates capture relative changes rather than causal effects of legalization.

Overall, the discussion of these findings points to divergence in relative trends rather than abrupt changes in cognitive performance. The modest size of the estimated differences and their consistency with the descriptive evidence suggest that cognitive outcomes evolved gradually across countries, shaped by demographic composition, education systems, and broader social developments during the decade observed.

While the findings here should be viewed as descriptive, not causal, they do point toward a useful direction for future work. A promising next step would be to create synthetic cohorts, where a weighted mix of control countries is chosen to closely mirror Canada before legalization. Canada's post-legalization outcomes could then be compared to this synthetic version to isolate how its trajectory differs. This method, however, requires a larger set of comparable countries observed in both 2012 and 2022, as well as more than one treated country to generate reliable weights. Because such data are not currently available, this remains a potential extension rather than something that can be implemented here. Still, a synthetic cohort approach could strengthen the ability to interpret Canada's trend in a broader policy context.

7 Conclusion

This thesis explores whether national patterns in cognitive skills changed differently in Canada compared with Germany and Ireland between 2012 and 2022, a period that includes Canada's move to legalize recreational cannabis. Using harmonized PIAAC data and a difference-in-differences approach, the analysis tracks how literacy, numeracy, and problem-solving scores shifted across countries over time. The focus is on comparing broad trends rather than measuring the direct cognitive effects of cannabis use.

The results show that cognitive performance increased in all countries over the decade, but the size of these gains varied. Canada experienced a smaller improvement relative to the pooled comparison group, and this pattern appeared consistently across descriptive statistics and regression estimates. The magnitude of the differences was modest, suggesting gradual divergence rather than abrupt shifts in national skill levels. These findings align with the idea that cognitive outcomes reflect multiple overlapping influences, including demographic aging, educational attainment, and country-specific developments, rather than a single policy event.

The analysis also illustrates the value of standardized, repeated assessments for tracking national skill distributions. While much of the existing literature focuses on clinical samples or self-reported measures, population-based data provide a broader perspective on how cognitive performance changes over time. At the same time, the study is limited by the availability of only two survey waves and the absence of information on individual cannabis consumption, which prevents stronger inferences about mechanisms.

Future research could build on this work by using longitudinal data, incorporating additional post-legalization survey cycles, and studying countries that legalize cannabis in later years. Such extensions would help clarify whether the patterns observed here persist, narrow, or widen over time and whether they differ across age groups or levels of use. Overall, the findings point to gradual differences in how national cognitive outcomes evolved across countries, reinforcing the importance of interpreting large-scale policy environments within a broader social and economic context.

8 Use of Generative AI and AI-assisted Tools

During the preparation of this thesis, I used ChatGPT for LaTeX formatting, obtaining certain LaTeX codes for creating equations, tables and figures, and fixing grammatical errors that I missed. After using this tool, I reviewed and edited the content as needed and take full responsibility for the content of my thesis.

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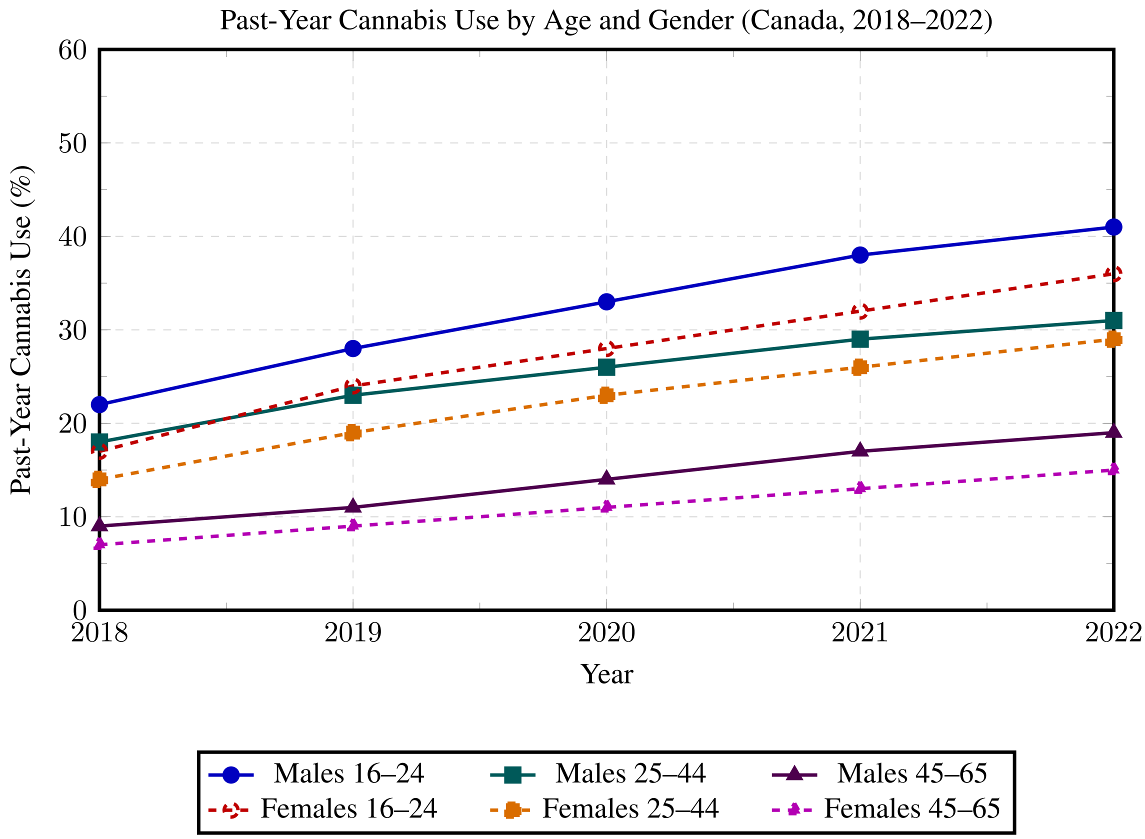
Appendix

Figure 1: Trends in Past-Year Cannabis Use by Age Group and Gender, Canada 2018–2022



Source: Canadian Cannabis Survey (2022) and Health Canada national surveys (CTADS 2013–2015; NCS 2018). Sample restricted to individuals aged 16 and older.

Table 1: Cannabis Consumption in Canada, 2022 (Adults)

Category	Indicator	Prevalence (%)
Overall use	Any cannabis use in past 12 months	27.0
By age group	16–19 years	36.0
	20–24 years	50.3
	25+ years	24.7
By education level	High school or less	33.1
	College/CEGEP diploma	25.9
	University degree	19.1
By immigrant status	Born in Canada	30.8
	Not born in Canada	16.1
By frequency of use	Daily / almost daily	19.2
	Weekly / several times a week	22.5
	Monthly / a few times a year	30.4
By method of consumption	Smoking (dried flower or joint)	69.4
	Edibles (food or drinks)	42.8
	Vaping (liquid or flower)	37.6

Source: Canadian Cannabis Survey (2022). Sample restricted to individuals aged 16 and older.

Table 2: Summary Statistics — Native-born Canadians (2012 vs 2022)

	2012				2022			
Variable	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Continuous variables:								
Literacy score	270.29	46.24	82.71	394.03	277.90	47.05	87.64	415.76
Numeracy score	259.62	51.28	63.69	409.13	274.23	49.53	24.52	445.08
Problem-solving score	278.58	41.20	130.66	396.15	263.72	39.60	72.44	388.34
Average cognitive score	266.35	46.60	73.20	394.26	271.95	44.01	79.19	404.26
Years of schooling	12.71	2.69	6.00	22.00	13.35	2.50	7.00	23.00
Categorical variables (proportions):								
Female	0.538				0.538			
Age group:								
18–24	0.1745				0.1195			
25–34	0.1613				0.1569			
35–44	0.1825				0.1943			
45–54	0.2419				0.2042			
55–65	0.2399				0.3250			
Education category:								
Low (≤5 years)	0.08				0.05			
Medium (6–10 years)	0.21				0.17			
High (11–14 years)	0.31				0.29			
Very High (15–18 years)	0.33				0.36			
Postgraduate (>18 years)	0.07				0.13			
Observations	8,893				9,088			

Notes: Continuous variables reported as weighted means, standard deviations, minima, and maxima. Categorical variables reported as weighted proportions (mean of dummy variables). Sampling weights (SPFWT0) applied. Sample restricted to native-born Canadians aged 18–65. Source: PIAAC 2012 and 2022.

Table 3: Summary Statistics — Native-born Germans (2012 vs 2022)

	2012				2022			
Variable	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Continuous variables:								
Literacy score	273.6	44.3	101.5	393.3	285.7	46.1	58.1	412.8
Numeracy score	275.5	49.2	72.2	418.2	290.0	49.7	21.4	421.3
Problem-solving score	285.8	40.5	145.5	411.6	275.9	39.6	116.4	396.4
Average cognitive score	283.1	39.7	151.4	404.0	283.9	43.8	60.2	402.6
Years of schooling	13.8	2.9	6.0	20.0	14.4	2.8	7.0	21.0
Categorical variables (proportions):								
Female	0.52				0.51			
Age group:								
18–24	0.16				0.09			
25–34	0.20				0.21			
35–44	0.22				0.24			
45–54	0.24				0.23			
55–65	0.18				0.23			
Education category:								
Low (≤5 years)	0.09				0.06			
Medium (6–10 years)	0.23				0.18			
High (11–14 years)	0.30				0.31			
Very High (15–18 years)	0.32				0.36			
Postgraduate (>18 years)	0.06				0.09			
Observations	5,379				3,876			

Notes: Continuous variables reported as weighted means, standard deviations, minima, and maxima. Categorical variables reported as weighted proportions (mean of dummy variables). Sampling weights (SPFWT0) applied. Sample restricted to native-born Germans aged 18–65. Source: PIAAC 2012 and 2022.

Table 4: Summary Statistics — Native-born Irish Adults (2012 vs 2022)

	2012				2022			
Variable	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Continuous variables:								
Literacy score	268.91	43.10	108.55	390.26	267.34	44.93	85.86	391.72
Numeracy score	256.88	49.40	36.22	392.24	261.97	49.54	61.67	410.97
Problem-solving score	276.27	37.17	153.25	385.39	250.30	39.11	101.86	371.68
Average cognitive score	263.45	44.11	90.31	376.52	259.87	42.96	101.14	389.21
Years of schooling	14.66	3.28	8.0	21.0	15.13	3.85	8.1	22.0
Categorical variables (proportions):								
Female	0.542				0.542			
Age group:								
18–24	0.126				0.110			
25–34	0.216				0.141			
35–44	0.262				0.257			
45–54	0.189				0.231			
55–65	0.207				0.260			
Education category:								
Low ($\leq$5 years)	0.02				0.04			
Medium (6–10 years)	0.05				0.12			
High (11–14 years)	0.20				0.34			
Very High (15–18 years)	0.55				0.51			
Postgraduate (>18 years)	0.18				0.08			
Observations		4,771				2,860		

Notes: Continuous variables reported as weighted means, standard deviations, minima, and maxima. Categorical variables reported as weighted proportions (mean of dummy variables). Sampling weights (SPFWT0) applied. Sample restricted to native-born Irish adults aged 18–65. Source: PIAAC 2012 and 2022.

Table 5: Welch t-test Comparison of Mean Values: Canada vs. Germany and Ireland (2012)

Variable	Canada	Germany+Ireland	Welch p-value
Cognitive Scores			
Literacy score	270.29	271.42	0.0838
Numeracy score	259.62	266.76	0.0000
Problem-solving score	278.58	281.82	0.0000
Average cognitive score	266.35	269.95	0.0000
Years of schooling	12.71	13.69	0.0000
Demographics			
Female share	0.538	0.525	0.0636
Age Group Shares			
Age 18–24	0.175	0.164	0.0519
Age 25–34	0.161	0.198	0.0000
Age 35–44	0.183	0.231	0.0000
Age 45–54	0.242	0.217	0.0000
Age 55–65	0.240	0.190	0.0000
Observations	8,893	10,150	–

Notes: Welch unequal-variance t-test. Germany and Ireland are pooled to form the control group. Values weighted using PIAAC sampling weights (SPFWT0).

Table 6: Difference-in-Differences Regression Results, 2012–2022

	All Skills	**Literacy**	**Numeracy**	**Problem Solving**
Main effects:				
Treated (Canada)	0.039***	0.052***	0.020***	0.030***
	(0.005)	(0.005)	(0.006)	(0.004)
Time effect (2022)	0.505***	0.520***	0.604***	0.344***
	(0.016)	(0.016)	(0.021)	(0.014)
Treatment effect (DiD)	-0.061***	-0.056***	-0.058***	-0.054***
	(0.007)	(0.007)	(0.008)	(0.006)
Cohort transitions:				
25–34 → 35–44	-0.062***	-0.066***	-0.064***	-0.060***
	(0.006)	(0.007)	(0.007)	(0.006)
35–44 → 45–54	-0.118***	-0.119***	-0.115***	-0.120***
	(0.008)	(0.008)	(0.010)	(0.007)
45–54 → 55–65	-0.176***	-0.169***	-0.162***	-0.177***
	(0.006)	(0.006)	(0.007)	(0.006)
Age (ref: 18–24):				
25–34	-0.057***	-0.048***	-0.052***	-0.050***
	(0.006)	(0.006)	(0.007)	(0.006)
35–44	-0.020***	-0.005	-0.010	-0.018**
	(0.007)	(0.008)	(0.009)	(0.007)
45–54	-0.006	0.005	-0.002	-0.005
	(0.006)	(0.006)	(0.008)	(0.006)
55–65	Reference	Reference	Reference	Reference
Controls:				
Female	-0.022***	-0.004	-0.048***	-0.006
	(0.006)	(0.006)	(0.006)	(0.005)
Years of schooling	0.050***	0.050***	0.059***	0.039***
	(0.002)	(0.002)	(0.002)	(0.001)
Constant	5.053***	5.034***	4.933***	5.223***
	(0.021)	(0.020)	(0.028)	(0.018)
Observations	27,025	27,025	27,025	24,708
R^2	0.209	0.198	0.183	0.198
Root MSE	0.165	0.171	0.202	0.145

Notes: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Models use PIAAC sampling weights (SPFWT0) and include cohort and age fixed effects, gender, and years of schooling controls. The treatment effect corresponds to the DiD estimator comparing changes in Canada relative to changes in the comparison group.