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Empirical Analysis of Obesity Determinants and Prevalence – The Case of Canada

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Obesity has recently developed into a global epidemic. This study follows an integrated approach of examining the determinants and prevalence of obesity in Canada. A multimethod analysis revealed that almost two-thirds of Canadians are overweight or obese. It was found that males, the aged, the married, the less educated, physically inactive people, and people with poor self-rated health have increased probability of being overweight/ obese. Several regulatory policy options which could reduce the incidence of obesity and, in turn, increase social welfare and individual well-being are discussed.

Keywords: *obesity, determinants, prevalence, government policies and regulations*

Introduction

Obesity is increasingly becoming a major health risk in Canada and the world at large. More than 1.9 billion adults aged 18 years and over were overweight (39% of adults); of these over 650 million were obese (13% of adults) in 2016 worldwide (WHO 2021)[1]. Mounting evidence in the literature suggests that obesity is the main risk factor for cerebrovascular diseases (e.g., hypertension and stroke), heart disease and diseases of pulmonary circulation, diabetes, and cancer (e.g., Alter et al. 2012, Birmingham et al. 1999, Lebenbaum et al. 2018, Tan et al. 2011, Sarma et al. 2021). Policies that could reduce the rising morbidity and mortality rates, accompanied by increasing health care expenditures and negative obesity externalities, are of increasing importance to the nation[2].

The severity of the obesity epidemic has attracted several empirical studies into the causes and determinants of obesity. Several studies have been conducted to estimate the prevalence of overweight and obesity and/or to analyse the various determinants of obesity (e.g., Alter et al. 2012, Batal and Decelles 2019, Bélanger-Ducharme and Tremblay 2005, Edwards 2007, Hajizadeh et al. 2016, Huot et al. 2004, Janssen et al.2020, Javed et al. 2022, Kaplan et al. 2003, Katzmarzyk 2002, Mandal and Chern 2006, Ogden et al. 2006, Peralta et al. 2018, Shields 2006, Statistics Canada

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[1]World Health Organisation (WHO) defines overweight and obesity for adults as follows: overweight is a Body Mass Index (BMI) greater than or equal to 25, and obesity is a Body Mass Index (BMI) greater than or equal to 30. While Body Mass Index (BMI) is defined as a person's weight in kilograms divided by the square of his height in meters (kg/m^2) WHO (2021).

[2]For more details, see Safaei et al. (2021), Tremmel et al. (2017), Kent et al. (2017), and WHO (2017).

2019, Tjepkema 2006, Ward et al. 2007). Many of these studies have employed different analytical techniques in attempts to establish a relationship between obesity and certain sociodemographic/socioeconomic and lifestyle factors.

Consequently, several socioeconomic and sociodemographic factors have been identified as significant determinants of overweight and obesity: age, gender, race, marital status, income, education, smoking status, alcohol use, fruits and vegetables consumption, comorbidity, physical activity, current BMI (Body Mass Index) status, etc. Moreover, such studies have also attempted to identify groups of people who are at risk of being obese as compared to the normal. The relationships were, however, not universal across studies on overweight/obesity and there were also some significant variations in the relationships. Overall, the important issue of obesity has not been adequately addressed in the literature, especially in Canada.

The current study attempts to shed light on the obesity epidemic and represents a step towards a better understanding of the economics of obesity. In particular, the goal of this study is to identify the major factors that significantly contribute to the incidence of obesity and propose policy measures to address those factors. The study analyses the socioeconomic and sociodemographic characteristics of obesity in Canada. Specifically, the paper evaluates the risk factors and determinants of obesity. In addition, it estimates overweight and obesity prevalence in Canada using measured data. Based on the findings from the study, it is also discussed how implementation of some regulatory policies and initiatives could help reduce the incidence of obesity and its associated cost in Canada. The results and policy implications of the study could be extended and are applicable to other countries and jurisdictions as well.

The study follows an integrated and multidisciplinary approach of estimating the prevalence of overweight and obesity in Canada as well as examining the socioeconomic and sociodemographic determinants of obesity in Canada using data collected in various surveys by Statistics Canada. In particular, this study uses data from the Canadian Community Health Survey provided by Statistics Canada to evaluate the socioeconomic and demographic characteristics of obesity based on a Multilevel Multinomial Logistic Regression Model (i.e., hierarchical modelling). Further, the study analyzes how implementation of government policies and regulations could help reduce obesity incidence, which, in turn, could reduce health care expenditures in Canada. Policy implications and recommendations that could improve social welfare and increase overall well-being are discussed.

Obesity has become a crisis that is not just a pressing health concern but also a threat to the global economy. Given the significant impact that a healthy diet and public policies can play in the reduction of the incidence of obesity and its associated chronic diseases and burdens on society, the study provides vital findings and recommendations regarding the pressing health and economic concerns of obesity.

The paper begins by describing the methods of analysis and data used in the study followed by estimates of the prevalence and determinants of obesity. A discussion of the study's results and policy implications closes the paper.

Methods of Analysis

This section provides a detailed discussion and justification of the method used for the analysis and describes the nature and source of data used. The section discusses the derivation of the econometric model used (i.e., the Multilevel Multinomial Logistic Regression Model) and justify its choice. Due to the categorical or ordinal nature of the dataset, including the main variable of interest—BMI (Body Mass Index), the Discrete Choice types of models are the most appropriate tool for this type of analysis. The two most often used models in the literature are the Multinomial Probit regression and the Multinomial Logistic regression. Although both models produce similar results, considering the ease of computation and the frequent usage of the Multinomial Logistic model in the empirical literature, the latter is used to perform the analysis. To incorporate the heterogeneity among the Canadian provinces into the analysis, we use a Multilevel Multinomial Logistic Regression Model (MMLRM). The province-level data is incorporated into the individual-level through a random intercept hierarchical model. Specifically, the study follows the hierarchical or multilevel modeling used by Raudenbush and Bryk (2002). Please see Appendix 1 for the full description of the model.

Data

The present study used confidential micro-level measured data from the latest available Canadian survey - the 2015 Canadian Community Health survey (CCHS) provided by Statistics Canada. The 2004 CCHS 2.2 data also were used to re-run the analysis to check the consistency of the results[3]. Both the 2015 and 2004 CCHS data were based on measured heights and weights. Research has shown that data based on self-reported heights and weights sometimes underestimate the prevalence of obesity (Bélanger-Ducharme and Tremblay 2005, Goldman et al. 2011, Le Petit and Berthelot 2005, Tjepkema 2006, Torrance et al. 2002).[4] A reasonable explanation of this problem is that people are more inclined to overestimate their height and underestimate their weight when self-reporting (Tjepkema 2006). Therefore, it is important to use data based on measured heights and weights.

Although other versions of the dataset like the annual CCHS exist, the 2015 and 2004 CCHS were chosen because most of the annual versions are based on

[3]Detailed findings from the 2004 CCHS 2.2 is available upon request.

[4]The comparison of the 1978-1979 Canada Health Survey (measured data) to the 1981 Canada Fitness Survey (self-reported data) by Torrance et al. (2002) indicated that, while the latter reported the percentage obese to be 9 percent, the former reported the percentage of people obese to be 13 percent. Moreover, comparing the 1988 Campbell Survey on Well-Being (self-reported data) with the 1986-1992 Heart Health Survey (measured data) also revealed that the percentage of people obese was 10 percent and 14 percent respectively. In addition, the estimated percentage of Canadians obese in 2003 (estimate based on self-reported heights and weights) was 15.2 percent, which is significantly below the 2004 estimate of 23.1 percent, which was based on measured heights and weights (Tjepkema 2006).

self-reported BMI. Furthermore, they do not focus on nutrition. The 2015 CCHS collected data on persons aged 1 and above in all ten provinces in Canada. The overall sample size of the 2015 CCHS was 20,487. The 2015 CCHS sampling strategy was designed to project the sample to the Canadian population (i.e., the sample is a fair representation of the population). The sampling weight provided by the 2015 CCHS was used in the estimations. For a detailed discussion on the sampling weight of the 2015 CCHS, refer to 2015 CCHS user guide provided by Statistics Canada. The groups of people excluded from the survey include: full-time members of the Canadian Forces, people living in the Territories, First Nation Reserves or Crown Lands, in prisons or care facilities and some remote areas. In addition, people aged below 18 years were excluded from the analyses because the emphasis of the studies was on adult obesity in Canada. By excluding people younger than 18 years from the analyses, the sample size was reduced to 14,200 (rounded). After deleting individuals with only self-reported heights and weights, non-responses, and missing data, the final sample size was 9,300.

Results and Discussion

Results from the Multilevel Multinomial Logistic Regression Model (MMLRM)

This section presents and discusses the results from the descriptive statistics and the econometric models (MMLRM). To test whether the use of the hierarchical modeling (i.e., MMLRM) was appropriate for the dataset, we estimated the variance of the random component at the provincial level, which was found to be significantly different from zero. In addition, the results from a likelihood ratio test indicated that the MMLRM fit considerably better than the simple multinomial logistic regression model (LR = 51.16 with p −value = 0.000).

Analysis of the 2015 CCHS data suggested that the prevalence of overweight and obesity among Canadian adults was 35.24 percent and 26.97 percent, respectively[5]. We found about 35.15 percent of Canadian adults to be of normal weight, while 2.64 percent were classified as underweight[6]. Table 1 presents the findings from the econometric model (MMLRM). Normal weight was selected as the reference BMI category. The first column under each BMI classification reports the odds ratios from the MMLRM[7]. The second and third columns report the standard errors and the p-values, respectively, associated with the model estimates.

[5]'Canadian adults' refers to Canadians aged 18 years and above.

[6]Analysis of the 2004 CCHS 2.2 data suggested that the prevalence of overweight and obesity among Canadian adults was 36.59 percent and 24.07 percent respectively. We found about 37.77 percent of Canadian adults to be of normal weight, while 1.58 percent were classified as underweight.

[7]Odds ratios above one indicate increased odds of overweight/obesity while odds ratios below one indicate reduced odds of overweight/obesity. The interpretation could be done using percentages by subtracting one from the odds ratio and multiplying the results by 100. For example, an odds ratio of 1.23 for overweight could be interpreted as 23 percent increased odds of becoming overweight.

Table 1. *Multilevel Multinomial Logistic Regression Results*

Variables	Overweight			Obese		
	O.R	S.E	P>z	O.R	S.E	P>z
Age groupings:						
18-24 (reference)						
25-34	1.642	0.191	0.000	2.416	0.335	0.000
35-44	1.882	0.230	0.000	3.483	0.493	0.000
45-54	2.217	0.272	0.000	3.893	0.552	0.000
55-64	2.352	0.301	0.000	3.515	0.521	0.000
65-74	2.675	0.369	0.000	3.433	0.544	0.000
75+	1.578	0.237	0.002	1.324	0.229	0.105
Sex:						
male (reference)						
female	0.508	0.028	0.000	0.626	0.038	0.000
Marital status:						
Married (reference)						
commom law	0.920	0.087	0.379	0.890	0.091	0.253
widowed	0.915	0.100	0.418	0.848	0.100	0.160
separated/divorced	0.883	0.083	0.184	0.895	0.089	0.267
single, never married	0.615	0.050	0.000	0.701	0.062	0.000
Country of birth:						
Canada (reference)						
other North America	0.925	0.247	0.770	0.910	0.264	0.745
South, Central America and Caribbean	1.348	0.215	0.061	1.100	0.190	0.581
Europe	1.054	0.114	0.627	0.770	0.094	0.031
Africa	1.292	0.245	0.178	0.558	0.137	0.017
Asia	0.608	0.052	0.000	0.212	0.024	0.000
Education:						
Less than high school diploma or its equivalent (reference)						
High school diploma or a high school equivalency certificate	0.938	0.085	0.484	0.857	0.081	0.104
Trade certificate or diploma	0.881	0.104	0.283	0.810	0.100	0.086
College/CEGEP/other non-university certificate or diploma	0.923	0.090	0.411	0.769	0.079	0.011
University certificate or diploma below the bachelor's level	0.965	0.142	0.807	0.656	0.108	0.011
Bachelor's degree (e.g. B.A., B.Sc., LL.B.)	0.802	0.082	0.032	0.554	0.062	0.000
University certificate, diploma, degree above the BA level	0.666	0.080	0.001	0.421	0.058	0.000
Household income grouping:						
Less than $5,000 (reference)						
$5,000 TO $9,999	0.634	0.226	0.200	0.815	0.333	0.616
$10,000 TO $14,999	1.031	0.321	0.921	1.434	0.522	0.322
$15,000 TO $19,999	1.254	0.370	0.442	1.470	0.517	0.273
$20,000 TO $29,999	1.232	0.348	0.460	1.428	0.486	0.295
$30,000 TO $39,999	1.145	0.323	0.632	1.404	0.478	0.318
$40,000 TO $49,999	0.949	0.268	0.853	1.287	0.437	0.458
$50,000 TO $59,999	1.230	0.351	0.468	1.555	0.534	0.199
$60,000 TO $79,999	1.266	0.361	0.408	1.427	0.492	0.302
$80,000 or more	1.069	0.293	0.807	1.541	0.512	0.193
Physical activity (150 minutes physical activity per week):						
Respondent met the physical activity guideline minimum (reference)						
Not met the physical activity guideline- minimum	0.978	0.052	0.676	1.252	0.073	0.000

Self-rated health:						
poor (reference)						
fair	1.592	0.353	0.036	1.283	0.253	0.206
good	1.621	0.335	0.019	0.931	0.170	0.695
very good	1.411	0.291	0.095	0.545	0.100	0.001
excellent	1.065	0.224	0.766	0.317	0.061	0.000
Has chronic condition:						
No (reference)						
Yes	1.250	0.090	0.002	2.027	0.154	0.000
Type of smoker:						
daily smoker (reference)						
occasional smoker	1.256	0.170	0.092	1.413	0.214	0.023
Not at all	1.272	0.100	0.002	1.791	0.153	0.000
Alcohol consumption (% total energy intake from alcohol):						
Present (reference)						
Absent	1.201	0.066	0.001	1.235	0.074	0.000
Cons:	0.539	0.200	0.097	0.327	0.135	0.007

Source: Authors' calculation.

The analysis and discussion of results is limited to normal weight, overweight and obesity since the focus of this study is not on the underweight category of BMI[8].

Except for people aged 75 and above, all the age groups are significantly associated with an increased risk of being overweight or obese when compared to the reference age group of 18 to 24. For instance, the 35-44 age group have odd ratios 1.882 and 3.483 of being overweight and obese, respectively. Although there is a progressively positive relationship between age and the likelihood of being overweight or obese, the relationship breaks down after the age of 74 years for the overweight category and 54 years for the obese category[9]. This result is consistent with most findings from other studies (Alter et al. 2012, Bélanger-Ducharme and Tremblay 2005, Mandal and Chern 2006, Ogden et al. 2006, Shields 2006).

Females were significantly less likely to be overweight or obese as compared to males with odds ratios of 0.508 for overweight females and 0.626 for obese females. A significant number of studies also have reported similar findings (Bélanger-Ducharme and Tremblay 2005, Edwards 2007, Huot et al. 2004, Kaplan et al. 2003, Katzmarzyk 2002, Mandal and Chern 2006). This result is not surprising, as relatively more females seem to be concerned with their appearance and a lot of cosmetic and weight loss programs and commercials target women.

All the variables under marital status were observed to have lower probability to be overweight or obese when compared to the married variable. For example, the single/never-married category showed a significantly lower probability to be

[8]For the purpose of all the analysis in the study, unless otherwise stated, significance is assumed to refer to a 5 percent level.

[9]See Figure 1 in the Appendix 2 for pictorial view of this relationship.

overweight or obese when compared to the married person in the same category. A possible explanation for such results is that singles might want to stay in good shape to attract a marriage partner (Edwards 2007).

People born in Asia were significantly less likely to be overweight/obese than people born in Canada. People born in Europe and Africa also were observed to have lower probability of being obese when compared to people born in Canada. The results for people born in the U.S., South America, Central America and the Caribbean were inconclusive as they were not statistically significant different than those born in Canada.

People with higher education were less likely to be obese when compared to people with lower levels of education (i.e., less than high school diploma or its equivalent). For example, people with university certificates, diplomas, or degrees above the BA level were observed to be significantly less likely to be overweight/obese when compared to people with less than high school diploma or its equivalent. This result is consistent with the findings of many previous studies. Generally, evidence suggests that the probability of being overweight or obese is lower as the education level increases (Edwards 2007, Huot et al. 2004, Kaplan et al. 2003, Mandal and Chern 2006, Oliver and Hayes 2005, Tan et al. 2011, Ward et al. 2007).

Surprisingly, people from the high household income categories were more likely to be overweight or obese in comparison to people from the lowest household income category[10]. A possible explanation of this result is that, in the quest to amass wealth, people might spend too much time at their workplaces to the extent that they are unable to find sufficient time to exercise. Furthermore, increased wealth might increase sedentary activities— the rich might prefer driving to walking. Ward et al. (2007) and Edwards (2007) found similar results in their studies. These results, however, contradict the findings of several other studies that observed a negative relationship between income and BMI (Bélanger-Ducharme and Tremblay 2005, Le Petit and Berthelot 2005, Oliver and Hayes 2005, Shields 2006, Shields and Tjepkema 2006).

As expected, greater physical activity was observed to be negatively related to obesity. However, greater physical activity did not result in significant differences in the overweight category. Generally, the results agreed with most of the findings from previous studies (Constăngioară et al. 2009, Edwards 2007, Hajizadeh et al. 2016, Huot et al. 2004, Kaplan et al 2003, Le Petit and Berthelot 2005, Mandal and Chern 2006, Tjepkema 2006, Ward et al. 2007).

People who rate their health to be excellent were significantly less likely to be obese when compared with those who rate their health to be poor. This result is not surprising as obesity often has been associated with ill-health. Furthermore, the result was boosted by findings from the chronic condition variable. Those who responded "no" to having any chronic condition were found to be significantly less likely to be overweight or obese when compared to those who responded 'yes' to having at least one chronic condition. This agrees with the findings from most

[10]It is important to note that the results were not statistically significant at the standard level of significance. Further analysis using the same methods, however, with the 2004 CCHS provided similar results that were statistically significant.

studies that observed a relationship between the presence or health history of comorbidities and overweight/obesity (Huot et al. 2004, Kaplan et al. 2003, Mokdad et al. 2003, Tan et al. 2011, Tjepkema 2006).

We found that occasional smokers and those who had never smoked had increased risk of being overweight or obese when compared to daily smokers. People who had never smoked were observed to have the highest likelihood of becoming overweight or obese. The results agreed with findings from previous studies (Edwards 2007, Hajizadeh et al. 2016, Huot et al. 2004, Kaplan et al. 2003, Mandal and Chern 2006, Tan et al. 2011, Ward et al. 2007). Interestingly, increased alcohol consumption was significantly associated with reduced likelihood of overweight and obesity. This finding is consistent with the findings from most studies. In view of this, some studies recommend moderate drinking as a measure to tackle obesity (e.g., Kaplan et al. 2003, Smothers and Bertolucci 2001). However, it is important to note that considering the other health risks associated with smoking and alcohol consumption, caution must be taken when proposing any overweight or obesity intervention programs based on these findings.[11]

Summary and Conclusion

Obesity and its attendant conditions have become a principle public health concern worldwide. The main objective of this study was to identify the socioeconomic and sociodemographic determinants of obesity in Canada. We further estimated the prevalence of obesity in Canada by using the latest available nationwide representative dataset based on measured heights and weights. By using descriptive statistics and an econometric model, we found that the prevalence of underweight, normal weight, overweight, and obesity among Canadian adults are 2.65 percent, 35.15 percent, 35.24 percent, and 26.97 percent, respectively. Hence, the analysis revealed that almost two-thirds of Canadians are overweight or obese. Additionally, groups of people that were observed to have increased probability of being obese include the aged, males, married, less educated, physically inactive, and people who consume fewer fruits and vegetables.

Specific policies should be directed to target certain groups of people who are at increased risk of the disease. Much of the awareness creation of the dangers of high caloric intake and obesity management education programs should be directed towards highly vulnerable groups. By critically analysing the

[11]Fruit and vegetable intake is an important factor to consider when analysing determinants of overweight/obesity. However, it was impossible to explicitly analyse their impact on obesity using the current data as it was one of the modules that the 2015 CCHS dropped. Therefore, using the same methods, we analysed the 2004 CCHS-Nutrition (which also is measured data) to find the relationship between obesity and fruit/vegetable consumption. As expected, an increase in consumption of fruits and vegetables was significantly associated with lower probability of overweight and obesity. The full results are available upon request. The findings were consistent with literature on the subject (Auld and Powell 2006, Edwards 2007, Hajizadeh et al. 2016, Mandal and Chern 2006, Shields 2006, Tjepkema 2006, Ward et al. 2007).

socioeconomic and sociodemographic determinants of obesity, we observed that certain groups of people are more vulnerable to this condition than others. For example, older people are at increased risk of becoming obese when compared to the younger generation. In addition, other groups that are observed to have increased odds of being obese include males, married, less educated, physically inactive, and people who consume fewer fruits and vegetables.

Furthermore, preventive education programs should be directed towards less vulnerable groups like the younger generation to help them minimise their probability of becoming overweight or obese. Obesity prevention programs could be incorporated into the education curriculum at various levels of schools. This would ensure that people get the necessary knowledge about causes of the condition at early stages of their lives.

Based on findings of this study, a number of policy recommendations are proposed. Specific policies such as obesity awareness and education programs should be directed towards groups of people that were observed to be at increased risk of being overweight or obese. Overall, this study recommends the following main intervention measures to tackle the obesity problem: nationwide introduction of obesity education campaigns, as well as potentially stronger economic measures such as the introduction of subsidies on healthy foods with low calorie contents, and the introduction of taxes on unhealthy foods with overblown calorie contents.

The findings of our study emphasize the need for interventions and policies to reverse the rising prevalence of obesity and minimize its health impacts. The study’s findings will also help policy and decision makers in priority setting and enactment of intervention measures aimed at effective promotion of healthy diets and physical activities. The prevalence of obesity has already reached epidemic proportions, which reinforces the need for the development of effective healthy lifestyle programs. Overall, there is a pressing need for public health measures to prevent (or, at least, to reduce) obesity and to save health care costs and societal resources.

References

Alter DA, Wijeysundera HC, Franklin B, Austin PC, Chong A, Oh PI, et al. (2012) Obesity, lifestyle risk-factors, and health service outcomes among healthy middle-aged adults in Canada. *BMC Health Services Research* 12(1): 238.

Auld MC, Powell LM (2006) The economics of obesity: research and policy implications from a Canada: US comparison. *Health Services Restructuring in Canada: New Evidence and New Directions* 108: 30.

Batal M, Decelles S (2019) A scoping review of obesity among indigenous peoples in Canada. *Journal of Obesity* 2019(Jun): 9741090.

Bélanger-Ducharme F, Tremblay A (2005) Prevalence of obesity in Canada. *Obesity Reviews* 6(3): 183–186.

Birmingham CL, Muller JL, Palepu A, Spinelli JJ, Anis AH (1999) The cost of obesity in Canada. *Canadian Medical Association Journal* (160): 483–488.

Constăngioară AM, Laslău MC, Constăngioară A (2009) Modern quantitative techniques used in the management of public health policy. *Romanian Economic Business Review* 4(4): 125–132.

Edwards M (2007) *An econometric analysis of overweight and obesity in Canada: evidence from cycle 2.2 of the Canadian Community Health Survey*. University of New Brunswick (Canada).

Goldman D, Lakdawalla D, Zheng Y (2011) *Food prices and the dynamics of body weight*. University of Chicago Press.

Grilli L, Rampichini C (2006) *A review of random effects modelling using gllamm in Stata*. Department of Statistics, University of Florence.

Hajizadeh M, Campbell MK, Sarma S (2016) A spatial econometric analysis of adult obesity: evidence from Canada. *Applied Spatial Analysis* 9(Apr): 329–363.

Huot I, Paradis G, Ledoux M (2004) Factors associated with overweight and obesity in Quebec adults. *International Journal of Obesity* 28(6): 766–774.

Janssen F, Bardoutsos A, Vidra N (2020) Obesity prevalence in the long-term future in 18 European countries and in the USA. *Obesity Facts* 13(5): 514–527.

Javed Z, Valero-Elizondo J, Maqsood MH, Mahajan S, Taha MB, Patel KV, et al. (2022) Social determinants of health and obesity: findings from a national study of US adults. *Obesity* 30(2): 491–502.

Kaplan MS, Huguet N, Newsom JT, McFarland BH, Lindsay J (2003) Prevalence and correlates of overweight and obesity among older adults: findings from the Canadian National Population Health Survey. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences* 58(11): M1018–M1030.

Katzmarzyk PT (2002) The Canadian obesity epidemic, 1985–1998. *Canadian Medical Association Journal* 166(8): 1039–1040.

Kent S, Fusco F, Gray A, Jebb SA, Cairns BJ, Mihaylova B (2017) Body mass index and healthcare costs: a systematic literature review of individual participant data studies. *Obesity Reviews* 18(8): 869–879.

Le Petit C, Berthelot J-M (2005) *Obesity: a growing issue*. Statistics Canada.

Lebenbaum M, Zaric GS, Thind A, Sarma S (2018) Trends in obesity and multimorbidity in Canada. *Preventive Medicine* 116(Nov): 173–179.

Mandal B, Chern W (2006) Econometric analysis of rising body mass index in the US: 1996 versus 2002. In *2006 Annual Meeting, July 23-26, Long Beach, CA* (No. 21136). American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association).

Mokdad AH, Ford ES, Bowman BA, Dietz WH, Vinicor F, Bales VS, et al. (2003) Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001. *Jama* 289(1): 76–79.

Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM (2006) Prevalence of overweight and obesity in the United States, 1999-2004. *Jama* 295(13): 1549–1555.

Oliver LN, Hayes MV (2005) Neighbourhood socio-economic status and the prevalence of overweight Canadian children and youth. *Canadian Journal of Public Health* 96(6): 415–420.

Peralta M, Ramos M, Lipert A, Martins J, Marques A (2018) Prevalence and trends of overweight and obesity in older adults from 10 European countries from 2005 to 2013. *Scandinavian Journal of Public Health* 46(5): 522–529.

Rabe-Hesketh S, Skrondal A, Pickles A (2002) Reliable estimation of generalized linear mixed models using adaptive quadrature. *The Stata Journal* 2(1): 1–21.

Rabe-Hesketh S, Skrondal A, Pickles A (2005) Maximum likelihood estimation of limited and discrete dependent variable models with nested random effects. *Journal of Econometrics* 128(2): 301–323.

Raudenbush SW, Bryk AS (2002) *Hierarchical linear models: applications and data analysis methods*. Volume 1. SAGE Publications.

Safaei M, Sundararajan EA, Driss M, Boulila W, Shapi'i A (2021) A systematic literature review on obesity: understanding the causes & consequences of obesity and reviewing various machine learning approaches used to predict obesity. *Computers in Biology and Medicine* 136(Sep): 104754.

Sarma S, Sockalingam S, Dash S (2021) Obesity as a multisystem disease: trends in obesity rates and obesity-related complications. *Diabetes, Obesity and Metabolism* 23(Suppl. 1): 3–16.

Shields M (2006) Overweight and obesity among children and youth. *Health Rep* 17(3): 27–42.

Shields M, Tjepkema M (2006) Trends in adult obesity. *Health reports/Statistics Canada, Canadian Centre for Health Information= Rapports sur la sante/Statistique Canada, Centre canadien d'information sur la sante* 17(3): 53–59.

Smothers B, Bertolucci D (2001) Alcohol consumption and health-promoting behavior in a US household sample: leisure-time physical activity. *Journal of Studies on Alcohol and Drugs* 62(4): 467.

Statistics Canada (2019) *Health fact sheets. Overweight and obese adults, 2018*. Available at: https://www150.statcan.gc.ca/n1/pub/82-625-x/2019001/article/00005-eng.htm.

Tan AK, Dunn RA, Samad MIA, Feisul MI (2011) Sociodemographic and health-lifestyle determinants of obesity risks in Malaysia. *Asia-Pacific Journal of Public Health* 23(2): 192–202.

Tjepkema M (2006) Adult obesity. *Health Reports-Statistics Canada* 17(3): 9–25.

Torrance G, Hooper M, Reeder B (2002) Trends in overweight and obesity among adults in Canada (1970-1992): evidence from national surveys using measured height and weight. *International Journal of Obesity and Related Metabolic Disorders: Journal of the International Association for the Study of Obesity* 26(6): 797–804.

Tremmel M, Gerdtham UG, Nilsson PM, Saha S (2017) Economic burden of obesity: a systematic literature review. *International Journal of Environmental Research and Public Health* 14(4): 435.

Ward H, Tarasuk V, Mendelson R (2007) Socioeconomic patterns of obesity in Canada: modeling the role of health behaviour. *Applied Physiology, Nutrition, and Metabolism* 32(2): 206–216.

World Health Organization – WHO (2017) *Assessing the economic costs of unhealthy diets and low physical acitivity: an evidence review and proposed framework*. WHO. Regional Office for Europe. Available at: https://apps. who.int/iris/handle/10665/326302.

World Health Organization – WHO (2021) *Obesity and overweight*. WHO. Available at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight#:~:text=Worldwide%%202%200obesity%20has%20nearly%20tripled,%2C%20and%2013%25%20were%20obese.

Appendix 1: Multilevel Multinomial Logistic Regression Model

The following two-level model is considered for the response variable R, which takes on the value of $m$with probability $\Pr(R = m) = j_m$ for $m = 1,\ldots,4$.

$$\begin{aligned}\Pr(R_{ij} = 1) &= j_{1,ij}\\ \Pr(R_{ij} = 2) &= j_{2,ij}\\ \Pr(R_{ij} = 3) &= j_{3,ij}\\ \Pr(R_{ij} = 4) &= j_{4,ij} = 1 - j_{1,ij} - j_{2,ij} - j_{3,ij}\end{aligned} \quad (1)$$

where, $R_{ij} = 1$ implies i^{th} individual from j^{th} province is underweight, $R_{ij} = 2$ implies i^{th}individual from j^{th}province is healthy, $R_{ij} = 3$ implies i^{th} individual from j^{th}province is overweight, and $R_{ij} = 4$ implies i^{th} individual from j^{th}province is obese. Then the MMLRM can be written as:

Level 1 model (individual): $\theta_{mil} = \beta_{0j(m)} + X'_{ij}\beta$ (2)
Level 2 model (province): $\beta_{0j(m)} = \alpha_{00(m)} + Z'_{0j(m)}\alpha + \mu_{0j(m)}$ (3)

where

$$\theta_{mil} = \log\left(\frac{\varphi_{mij}}{\varphi_{Mij}}\right) = \log\left(\frac{\Pr(R=m)}{\Pr(R=M)}\right), for\ m = 1,2,3. \quad (4)$$

The error term is not included in the level one model since θ_{mil} is already expressed as an expected value of the indicator variables for the various classifications of Body Mass Index (Mandal and Chern 2006); $\beta_{0j(m)}$ is the individual level intercept and β is the vector of coefficients corresponding to a vector of individual level predictor variables X_{ij}; $\alpha_{00(m)}$ is the intercept at the province level; and α is the vector of coefficients corresponding to a vector of province level predictor variables $Z_{0j(m)}$. The random component term $\mu_{0j(m)}$ has multivariate normal distribution with component means of 0 and variance-covariance matrix Σ, i.e.,

$$\mu_{0j(m)} \sim MN(0, \Sigma) \quad (5)$$

From (2) and (3), the combined model can be written as:

$$\theta_{mil} = \alpha_{00(m)} + X'_{ij}\beta + Z'_{0j(m)}\alpha + \mu_{0j(m)} \quad (6)$$

where the first three terms in (6) are the fixed part of the model and the last term in (6) is the random part of the model showing the variation among provinces. For simplicity, the slopes are assumed to be constant at all levels.

The conditional likelihood contribution of the j^{th} cluster can be written as a multivariate integral over the correlated error terms (Rabe-Hesketh et al. 2005). The likelihood contribution for a given cluster j can be written as:

$$f_{ij}^{(2)} = \int \phi(\mu_{0j(m)}) \prod_{i=1}^{n_j} f_{ij}^{(1)}(\xi|\mu_{0j(m)}) d\mu_{0j(m)}, \qquad (7)$$

where ξ is a vector of all the model parameters; $\phi(.)$ represents the normal density with mean 0 and covariance matrix Σ and $f_{ij}^{(1)}(.)$ is the conditional likelihood contribution of unit i in cluster j which can be written as:

$$f_{ij}^{(1)}(\xi|\mu_{0j(m)}) = R_{ij}\Phi(\theta_{mij}) + (1 - R_{ij})\Phi(-\theta_{mij}) \qquad (8)$$

where $\Phi(.)$ is the standard normal cumulative distribution function and R_{ij} is the response vector given in (1).

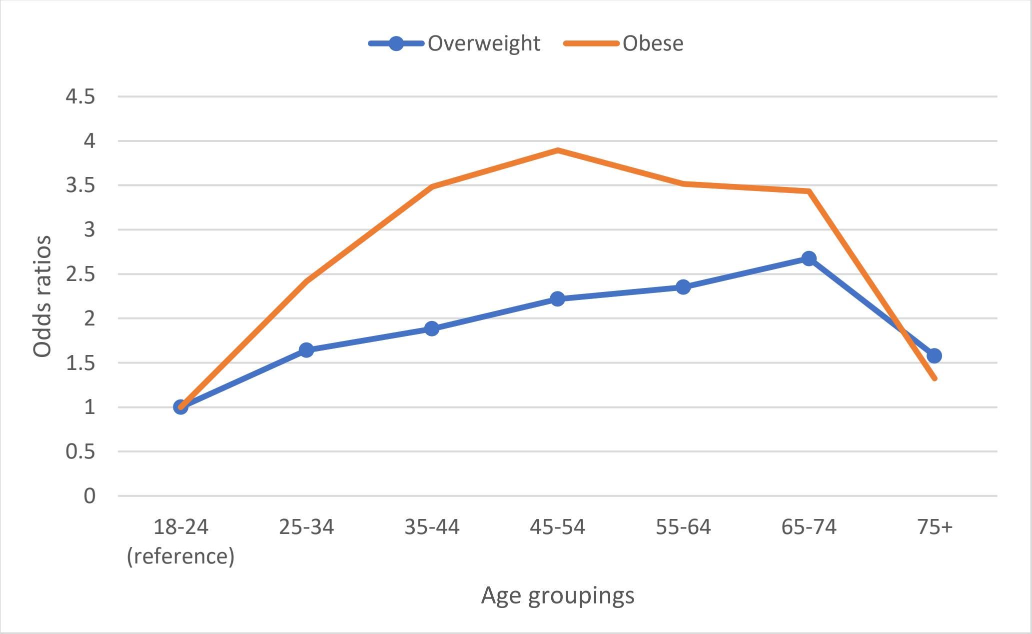
In order to estimate the MMLRM, we must evaluate and maximize the likelihood in (7) and (8). However, because of the complexity of the likelihood function due to the integral term in (7), it is very difficult to evaluate the likelihood contribution analytically. Therefore, it is necessary to approximate the maximum likelihood solution. One common approach to estimate the parameters is to evaluate the marginal likelihood numerically by applying Gauss-Hermite quadrature (Rabe-Hesketh et al. 2005). Specifically, we use the adaptive quadrature to evaluate and maximize the marginal log likelihood during the parameter estimation process due to its computational efficiency (Grilli and Rampichini 2006, Rabe-Hesketh et al. 2002). In addition, the integral in (7) is approximated using the numerical integration with 12 grid points. Increasing the number of grid points improves the approximation, however, in our experience, 12 points is often sufficient.

For clarity and ease of interpretation, the results from the MMLRM can be presented in terms of odds ratios by taking the exponential of equation (6). The MMLRM can be expressed in terms of odds ratios as follows:

$$\exp(q_{mil}) = \exp(a_{00(m)} + X_{ij}^{'}b + Z_{0j(m)}^{'}a + m_{0j(m)}) \qquad (9)$$

Appendix 2: Empirical Results

Figure 1. *Relationship between Age Group and Odds of Becoming Overweight/ Obese*



Source: Authors' calculation.