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# Physical Activity and Health Outcome: Evidence from Canada

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**Abstract**

Health production models include participation in physical activity as an input. We investigate the relationship between participation in physical activity and health using a bivariate probit model. Participation is identified with an exclusion restriction on a variable reflecting sense of belonging to the community. Estimates based on data from Cycle 3.1 of the Canadian Community Health Survey indicate that participation in physical activity reduces the reported incidence of diabetes, high blood pressure, heart disease, asthma, and arthritis as well as being in fair or poor health. Increasing the intensity and frequency of participation in physical activity appears to have a diminishing marginal impact on adverse health outcomes above the moderate level.

JEL Codes:
I12: Health: Production
I18: Health: Government Policy; Regulation; Public Health
Keywords: health production; physical activity; lifestyle choices; bivariate probit

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# 1 Introduction

Lifestyle choices, more narrowly defined as health-related behaviors, are widely recognized in the epidemiological and economics literature as important non-medical determinants of health. Belloc and Breslow (1972) analyzed survey data from a random sample of 7,000 residents in Alameda County in 1965 and identified seven lifestyle choices that are associated with better health. These seven lifestyle choices, also known as the "Alameda Seven", include: eating breakfast; maintaining proper weight; not snacking between meals; never smoking cigarettes; regular physical activity; moderate or no use of alcohol; and getting 7-8 hours of sleep regularly. The benefits of regular physical activity are well documented in the clinical and public health literature. Benefits include reduced risk of many chronic diseases, reduced stress and depression and increased emotional well-being, energy level, self-confidence and satisfaction with social activity (Sherwood and Jeffery (2000)). Seven chronic diseases have been consistently associated with physical inactivity: coronary heart disease, hypertension, stroke, colon cancer, breast cancer, type 2 diabetes, and osteoporosis. Physically inactive people are also more likely to be obese which is itself an important risk factor for many chronic diseases, including coronary artery disease stroke, hypertension, diabetes and cancer (see Brown et al. (2007); Warburton et al. (2006); Katzmarzyk and Janssen (2004); Sherwood and Jeffery (2000); and United States Surgeon General (1996) for reviews of the literature on the effects of physical activity on health and disease).

The economic costs of physical inactivity are undoubtedly substantial but difficult to accurately quantify since physical inactivity is one of several modifiable risk factors for some chronic diseases. In addition, the economic costs include the direct health care costs to treat diseases linked with physical inactivity as well as indirect costs such as work loss due to disability. Katzmarzyk and Janssen (2004) estimated the costs of physical inactivity to be $5.3 billion in Canada in 2001, or 2.6% of total health care costs. Sari (2009) estimated that moderately active individuals, compared with active individuals, use between 2.4% to 9.6% more health care services. Recent estimates from the United States of annual medical spending attributable to obesity were $147 billion per year in 2008, or about 10% of all health care spending (Finkelstein et al. (2009)). Sander and Bergemann (2003) estimated the economic burden of obesity for Germany in 2001 to be between €2.7 and €5.6 million per year. Although the U.S. and Germany studies are not specifically about the costs of physical inactivity, estimates of the economic costs of obesity provide some idea of the costs of physical inactivity since physically inactive people are more likely to be obese.

Given the health benefits of regular physical activity and the costs of physical inactivity, promoting regular physical activity is a public health priority in many countries. In Canada, the prevalence of meeting physical activity guidelines is improving but still remains low. A comparison of the results from the 1996/1997 National Population Health Survey (NPHS) with those from the 2005 Canadian Community Health Survey (CCHS) shows that Canadians who reported at least moderately active leisure time rose from 43% to 52% (Gilmour (2007)). Based on estimates from the 2003 and 2008 CCHS, the number of physically active Canadians rose from 13,389,032 in to 2003 to 13,924,281 in 2008 - a modest 4% increase (Statistics Canada (2010)). Two-thirds of adult Canadians (over age 20) do not meet the guidelines for sufficient physical activity as defined in Canada's Physical Activity Guide (Public Health Agency of Canada, 2006). This statistic is a motivating factor for the Canadian Sport Policy goal of enhancing Canadian's participation in sport and physical activity at all levels by 2012.

Although regular physical activity is commonly included in epidemiological studies as a health practice that is associated with good health, it has not been as extensively studied as a determinant of health in the health economics literature. In particular, questions about the frequency and intensity needed to provide health benefits remain. The objective of this paper is to examine the impact of physical activity on health outcomes. Motivated by the Grossman (1972) health production approach, we specify bivariate probit models of health outcomes and measures of physical activity. We estimate the structural parameters of the health outcome equation together with the reduced form parameters for the physical activity equation using data from the 2005 CCHS.

## 2 Economic Framework

The economic framework underlying the empirical analysis is Grossman's health production model (Grossman (1972)). Grossman builds on the concept of home production introduced by Becker (1965) to develop a model of the demand for health. The model links household production and investment in human capital theories in describing the demand for health by ascribing both a consumption and investment motive to health. Health is a consumption good because people derive satisfaction from being healthy. It is an investment good because it determines the total amount of time available for all activities. The health production framework motivates the econometric analysis of the relationship between non-medical inputs such as physical activity and health outcomes. In this framework, individuals are described by a utility function $U(C, H; X_U, \mu_U)$ where utility depends a stock of health (H) and on the consumption of other commodities ($C$). $X_U$ is a set of exogenous observable factors that affect utility and $\mu_U$ is a set of unobservable factors that affect utility. Commodities are produced by combining purchased market goods and time. Consumers invest in their stock of health by combining medical and non-medical inputs and time to produce health. The stock of health has the classic characteristic of an investment good that depreciates as people age. Individuals make choices about how to allocate their time and resources to health investments and other activities subject to time and monetary budget constraints.

Grossman posits that health is an investment good that depreciates with age. The health production model has been expanded to allow factors other than age to affect the stock of health. For example, the expanded health production model assumes that the stock of health is affected by health behaviors (or lifestyle choices). The health production function can be written as $H(L, X, M, N; H_{t-1}, E)$ where $H$ is the stock of health; $L$ is a vector of lifestyle choices or health-related behaviors; $X$ represents non-medical purchased inputs to health; $M$ is purchased medical inputs; $N$ is environmental inputs; $H_{t-1}$ is existing health stock and $E$ is education.

Health can be thought about as current health or future health, recognizing the influence of health behaviors on health is not immediate. Some activities, like smoking, may provide current utility but can be expected to decrease the stock of health over the long run. Conversely, other activities, like healthy eating habits and regular exercise may increase or decrease current utility but can be expected increase health stock net of normal depreciation.

The health production framework recognizes that individuals are heterogeneous in terms of health production. The investment in health realized by any individual depends on the initial endowment and decisions about engaging in healthy behaviors. The optimality conditions arising from this type of model describe the trade-offs individuals face between choices that provide direct satisfaction and other behaviors that improve health. In this context, physical activity is a health-promoting activity. The optimality conditions provide the basis for constructing and estimating empirical models of health outcomes.

## 3 Health Production Studies

The Grossman health production framework has been used in numerous empirical studies that examine the demand for health. This literature is quite diverse. The focus of the first studies was on the demand for health inputs, mainly medical care (for example, Goldman and Grossman (1978); Leibowitz and Friedman (1979)). However, Fuchs (1986) convincingly argued that lifestyle choices are responsible for a substantial portion of variation in health. Recognizing that variation in medical care utilization can only partially explain differences in health, a substantial literature has developed that explores the relationship between lifestyle choices (or health behaviors), education, income, and health.

The critical empirical challenges in the estimation of health production functions is accounting for unobservable individual heterogeneity and endogeneity of health inputs. Rosenzweig and

Schultz (1983) and Mullahy and Portney (1990) are among the first to tackle these issues by employing instrumental variable techniques to estimate single equation health production functions. Rosenzweig and Schultz (1983) estimated a health production function in which birth weight is the health outcome of interest. The inputs affecting birth weight are prenatal medical care, characteristics of the mother like employment status while pregnant, smoking while pregnant, age and number of births, prices and income. Mullahy and Portney (1990) examined the effect of cigarette smoking, air pollution, climatological conditions and other risk factors on the production of respiratory health. Treating smoking as an endogenous variable, they found that increased smoking results in more days of respiratory illness.

Several studies examine the effects of multiple lifestyle choices and health behaviors on various measures of health and health status. Kenkel (1995) used the 1985 Health Interview Survey data to examine the effects of the Alameda Seven on health in a health production framework. He estimated individual health production functions using five output measures: self-reported health status; presence of activity limitations; number of restricted activity days in the past two weeks; systolic blood pressure and a measure of proper weight. He found that excessive weight, cigarette smoking, heaving drinking, excessive or insufficient sleep and stress to have negative effects on health and harmful, while exercise and moderate alcohol consumption had positive effects on health.

Contoyannis and Jones (2004), Balia and Jones (2008) and Schneider and Schneider (2009) modeled the production of health as recursive structures with reduced form equations for health behaviors or lifestyle choices and a structural equation for the health production function. Contoyannis and Jones (2004) examined the effects of socioeconomic status and lifestyle on health. Using data from the 1984 and 1991 British Health and Lifestyle Survey (HALS), they estimated the structural parameters of a health production function together with the reduced form parameters for lifestyle equations. Health was measured by a binary indicator of self-assessed health status. The endogenous health behavior (lifestyle) variables were based on the Alameda Seven. They found that sleeping well, exercising and not smoking had positive effects on the probability of reporting excellent or good health but eating breakfast and moderate alcohol consumption were not indicators of health status.

The correlation between socioeconomic status and health is well documented in the literature. However, lifestyle choices may mediate the relationship between socioeconomic characteristics and health. Contoyannis and Jones (2004) in fact find this to be the case in their study of socioeconomic status, health and lifestyle. Balia and Jones (2008) also used the British HALS (1984 and 2003) to estimate the effects of lifestyle choices on mortality and evaluate their contribution to the observed socioeconomic gradient of mortality. Like Contoyannis and Jones (2004), health was measured by a binary indicator of self-assessed health status and the lifestyle variables are based on the Alameda Seven. Mortality was measured as a binary variable taking on the value of 1 if the respondent had died before the May 2003 survey and zero otherwise. Balia and Jones (2008) found that all of the lifestyle indicators had a negative sign but only non-smoking, eating breakfast and obesity were statistically significant. Regular exercise was not found to be an important determinant of health. They also found that lifestyle choices do indeed contribute in an important way to the socioeconomic gradient of mortality.

Schneider and Schneider (2009) examined the impact of smoking, alcohol consumption and obesity on self-assessed health status using data from the 2006 German Socio-economic Panel (SOEP). Like Contoyannis and Jones (2004) and Balia and Jones (2008), they estimated the structural parameters of a health production function and reduced form parameters of the three health behavior equations as a recursive system. They found differential effects of smoking, alcohol consumption and obesity on health status by gender. Drinking and obesity had a negative impact on male health but no significant effect of smoking was found. For females, drinking positively influenced health status but smoking and obesity were not significant.

Grossman (1972) incorporates an important role for education in the production of health by assuming that education increases the efficiency of household health production. Educational attainment is often found to be positively and strongly correlated with health outcomes or health status. However, empirically establishing the mechanisms through which education affects health is challenging because there are at least three alternative explanations about the structural relationship between education and health. The first view argues that there is a direct causal effect whereby additional education allows individuals to more effectively produce health with a given set of inputs. The second explanation is that unobserved factors such as preferences, upbringing and rate of time preference affect both health and education in the same direction. The third explanation is reverse causality, that is, better health allows one to attain a higher level of education.

Kenkel (1991, 1995) and Gilleskie and Harrison (1998) are examples of empirical studies of the causal relationship between schooling and health outcomes. Kenkel (1991) tests a hypothesis of allocative efficiency, that is, education improves the choice of health inputs or health behavior by improving an individual's health knowledge. Kenkel estimates the separate effects of health knowledge and schooling on (un)healthy behaviors of cigarette smoking, alcohol consumption and exercise. He finds that part of the relationship between schooling and health behavior is explained by differences in health knowledge but most of schooling's effects on health behavior still remain after controlling for differences in health knowledge. In a related paper, Kenkel (1995) explores the notion of productive efficiency by examining the effect of education on the marginal products of other health inputs like smoking, drinking, exercise and sleep habits. He finds that for some health measures, education increases the positive marginal products of healthy inputs and decreases the negative marginal product of some unhealthy inputs. Gilleskie and Harrison (1998) study both productive and allocative efficiency of schooling on health and find evidence of both.

This paper adds to the empirical literature on health production by focusing the effect of physical activity on several health outcomes that have been explicitly linked with physical activity in the clinical literature. Some of the previous studies include regular exercise as an input in the health production function (for example, Kenkel (1995); Contoyannis and Jones (2004); Balia and Jones (2008)). Kenkel and Contoyannis and Jones find that regular exercise is associated with better health but Balia and Jones do not find a significant effect of exercise on health status. We take a closer look at the role of physical activity in producing health by considering both the intensity and frequency of physical activity in our models.

## 4 Data Source - Canadian Community Health Survey (CCHS) 3.1

We use data from cycle 3.1 if the Canadian Community Health Survey (CCHS), public use microdata file. The CCHS is a nationally representative cross-sectional survey that collects health and sociodemographic information from a sample of household residents over the age of 12 in all 10 provinces and 3 territories. The CCHS excludes residents of health care institutions, residents living on Indian Reserves, Canadian Forces Bases and in some remote areas. Data collection for the CCHS cycle 3.1 was collected between January and December 2005. The CCHS 3.1 sample contains 132,221 persons (Statistics Canada (2006)).

The CCHS 3.1 has a complex survey design based on a three sampling frames to ensure sufficient sample size to produce reliable estimates at the geographic levels of the province and the sub-provincial level of the health region. To account for the CCHS's complex survey design, Statistics Canada produces sample weights and provides them with the public use micro data file (Statistics Canada (2006)).

The lifestyle variable of interest in this study is participation in physical activity. The CCHS asks detailed questions about participation in leisure time physical activity and contains a number of variables describing the type of participation and the intensity of participation. We use three derived binary variables to examine the effects of different levels of participation and intensity. The three levels of participation in physical activity are: (i) "active" level of participation, (ii) a "moderately active" level of participation, and (iii) daily participation. These three measures represent different levels of frequency and intensity of participation in physical activity which can be interpreted as choices available to individuals who become physically active. By devoting more time and effort to participation in physical activity, individuals can select themselves into one of these categories; these different levels of participation in physical activity may also affect the individual's stock of health.

The two binary variables "active participation" and "moderately active participation" are derived from the physical activity index (PAI). The PAI is based on the average daily energy expended (kcal/kg/day) on leisure time physical activity in the past three months. Energy expenditure is based on the frequency and duration of reported sessions of physical activity and the metabolic equivalent task (MET) value of the specific activity.[1] The MET is a value of metabolic energy cost expressed as a multiple of the resting metabolic rate. For example, an activity of 4 METS requires four times the amount of energy as compared to when the body is at rest. The first binary variable is an indicator for individuals who are physically active, which is is defined as having an average daily energy expenditure greater than or equal to 3. The second binary variable is an indicator for individuals who are moderately active, which is is defined as having an average daily energy expenditure greater than or equal to 1.5 and less than 3.

The third binary variable (daily participation in physical activity) is based on responses about leisure time physical activity over the previous three months. These three indicator variables identify individuals who engage in physical activity frequently and intensely. The binary variables for active participation and moderately active participation both reflect intensity and frequency of physical activity. The indicator variable for daily participation reflects high frequency participation but not intensity. This delineation in the physical activity variables should allow us to evaluate the extent and intensity of physical activity needed for health benefits.

Next, we focus on six health outcome variables: individuals who report being in fair or poor health, have diabetes, high blood pressure, heart disease, arthritis, or asthma. These are among the most frequently reported negative health outcomes in the CCHS. Most of these health outcomes, but specifically high blood pressure, diabetes and heart disease, have been linked to lifestyle choices and can be influenced by physical activity. Each health outcome is measured as a binary variable taking on the value of 1 if the individual reported having the condition and zero otherwise.

The analysis also includes a number of socioeconomic and demographic variables to control for other determinants of health. The demographic variables included in the model, but not discussed in detail here, include: age, sex, marital status, employment status, a binary variable equal to one if welfare is the household's primary source of income, a binary variable equal to one if the home

[1] The MET value is equal to the energy cost of the activity: (kcal/kg per hour)/365 (to convert yearly data into daily data)

is owned (not rented), a binary variable equal to one if there are kids (under the age of 12) in the household, Canadian born, province/territory of residence. Finally we also include height (in meters) as a continuous exogenous variable as it is a good predictor of mortality and morbidity risks and captures heterogeneity in initial health endowments (Balia and Jones (2008)).

The main economic variables of interest are household income and level of education. Household income is a categorical variable with categories: $0 - $14,999, $15,000 - $29,999, $30,000 - $49,999, $50,000 - $79,999, and $80,000 or more. Household income is not adjusted for household composition - such as marital status and the number of children living in the household. Rather, household composition variables are included as independent variables in the regression analysis. The categorical income variables allow us to account for differences in the relative income position of households in the analysis and for a nonlinear relationship between household income, physical activity and health. The level of education is a derived variable indicating the highest level of education attained by the individual: less than high school, high school graduate, some post secondary, and post secondary graduate.

The sample size of the full CCHS 3.1 is 132,221 observations. The analysis sample is restricted to respondents who are: (i) 18 years of age or older, and (ii) not missing information on any of the dependent variables. The restrictions result in an analysis sample size of 111,770.[2]

# 5 Empirical Methods

Empirical analyses of the effects of health-related behaviors on health pose an econometric challenge due to unobserved individual heterogeneity and the endogeneity of health and health-related behaviors. Accounting for unobserved individual heterogeneity is necessary if we want consistent parameter estimates. For example, a standard single equation model, which does not control for unobserved individual heterogeneity, would produce inconsistent parameter estimates.

One approach to control for unobserved individual heterogeneity is to use a single equation instrumental variable model, such as two-stage least squares (Lindahl (2005); Gilleskie and Harrison (1998); Mullahy and Portney (1990); Kenkel (1991, 1995); Rosenzweig and Schultz (1983) are examples). An alternative approach is to use a recursive multivariate probit model where a system of equations is specified for the health production function and health behaviors to control for unobserved individual heterogeneity and endogeneity (Contoyannis and Jones (2004); Balia and

[2]There were 12,317 individuals under 18 years of age and 8,134 observations dropped due to missing information for height, employment status, canadian born, and home ownership. One concern that may arise from the sample restrictions is how a systematic risk of selection into the sample may affect the results. Appendix Table A.1 compares the summary statistics from the full CCHS 3.1 sample with the summary statistics of the analysis sample.

Jones (2008); Schneider and Schneider (2009); Rascuite and Downward (2010)).

We take the second approach and estimate a recursive bivariate probit model to examine the relationship between participation in physical activity and health outcomes.

### 5.1 Recursive Bivariate Probit Model

Our recursive bivariate probit model is a two equation binary outcome model with correlated error disturbances and is defined as:

$$y^*_{pi} = \beta_p \mathbf{x}_{pi} + u_{pi}, \tag{1}$$

$$y^*_{hi} = \alpha y_{pi} + \beta_h \mathbf{x}_{hi} + u_{hi}, \tag{2}$$

where $y^*_{hi}$ is the latent stock of health for individual $i$, $y^*_{pi}$ is the latent benefit that individual $i$ derives from participation in physical activity. Since $y^*_{ji}$, $j = (p, h)$, is unobservable, we only observe $y_{ji}$, where $y_{ji} = 1$ if $y^*_{ji} < 0$, and zero otherwise. $\mathbf{x}_{ji}$ is a vector of explanatory variables, and $\beta_p$, $\beta_h$, and $\alpha$ are unknown parameters. The error terms ($u_{pi}$ and $u_{hi}$) are assumed to be distributed bivariate normal (with probability density function $\phi_2$ and cumulative density function $\Phi_2$), mean zero, constant variance, and $\text{corr}(u_{pi}, u_{hi}) = \rho$.

The correlation between the error terms ($u_{pi}$ and $u_{hi}$) derives from the assumption each error is comprised of two components: (i) unobserved individual heterogeneity ($\eta_i$); and (ii) a constant part unique to each model ($\epsilon_{pi}$ and $\epsilon_{hi}$ respectively):

$$u_{pi} = \eta_i + \epsilon_{pi},$$

$$u_{hi} = \eta_i + \epsilon_{hi},$$

If $\rho = 0$, then the bivariate probit is equivalent to two independent probit models.

Similar to the description in Greene (2008), the construction of the log-likelihood function is as follows. First, define $q_{ji} = y_{ji} - 1$, where $j = (h, p)$. Thus, $q_{ji} = 1$ if $y_{ji} = 1$ and $q_{ji} = -1$ if $y_{ji} = 0$. Second, define $z_{ji} = \gamma_j \mathbf{x}_{ji}$, $w_{ji} = q_{ji} z_{ji}$, and $\rho^*_i = q_{hi} q_{pi} \rho$. Thus, the probabilities that enter the likelihood function are:

$$\text{Prob}(Y_h = y_{hi}, Y_p = y_{pi} | \mathbf{x}_{hi}, \mathbf{x}_{pi}) = \Phi_2(w_{hi}, w_{pi}, \rho^*_i). \tag{3}$$

Using equation (3), the log-likelihood function is given by:

$$\log L = \sum_{i=1}^{n} \ln \Phi_2(w_{hi}, w_{pi}, \rho^*_i). \tag{4}$$

We estimate our recursive bivariate probit model using the bivariate probit (`biprobit`) command, with robust standard errors, in STATA/MP4 11. The `biprobit` command uses maximum likelihood to estimate equation (4).

Note the system is recursive. The physical activity equation (1) is a reduced form equation which depends on the exogenous variables ($\mathbf{x}_{pi}$). The health outcome equation (2) is a structural equation which depends on the exogenous variables ($\mathbf{x}_{hi}$) and participation in physical activity ($y_{pi}$). Maddala (1983) described methods for estimating recursive systems of equations like (1) and (2). In order for the parameters to be consistently estimated, the system must be identified. In this case, an explanatory variable must appear in $\mathbf{x}_{pi}$ that does not appear in $\mathbf{x}_{hi}$. In general, an exclusion restriction identifying participation in physical activity should be a variable that is related to participation but unrelated to $u_{hi}$. Our exclusion restriction was based on the variable describing an individual's "sense of belonging" to the local community. Forrest and McHale (2009) and Huang and Humphreys (2010) showed that individuals living in communities with more sport facilities are more likely to participate in leisure time physical activity. We assume that individuals who report a very strong or strong sense of belonging in the community are living in areas with either adequate local amenities including physical activity related facilities, or with a generally supportive culture that includes support for being physically active. These factors should be unrelated to the stock of health.

Wilde (2000) argued an exclusion restriction is not required to identify the parameters in the system of equations, as long as $\mathbf{x}_{pi}$ and $\mathbf{x}_{hi}$ each contain one varying explanatory variable. While this may be possible, we were unable to achieve convergence of any of the empirical models estimated without imposing an exclusion restriction. This suggest our case does not match the situation described by Wilde (2000).

# 6 Results

## 6.1 Descriptive Statistics

Table 1 presents summary statistics for the physical activity ($y_{pi}$) and health outcome ($y_{hi}$) variables. Section 1 shows participation in physical activity is relatively common as 36.2% participate daily, 24.5% are active participants, and 25.6% are moderately active participants. There is not complete overlap in the three categories of participation in physical activity, because daily participation does not reflect intensity of participation. Table 2 presents the number and proportion of respondents who participate daily by whether they are active participants or moderately active participants. Almost all (93.8%) of respondents who are active participants participated daily in physical activity, while only 43.1% of respondents who are moderately active participants participated daily in physical activity.

Section 2 of Table 1 presents the mean for the six health outcome measures. The proportion of respondents with one of the six health outcomes range from a low of 5.2% (diabetes and heart disease) to a high of 18.1% (arthritis).

Table 3 presents the number and proportion of people reporting one of the six health outcomes by their level of participation in physical activity. As shown in column (2), between 12.2% and 24.1% of respondents with a given health outcome are active participants in physical activity. This range increases slightly for respondents who are moderately active participants in physical activity as shown in column (4): between 18.7% and 25.0%. The highest proportion of respondents participate daily in physical activity: between 25.6% and 36.3%.

Table 4 presents summary statistics for the dependent variables ($\mathbf{x}_{pi}$ and $\mathbf{x}_{hi}$). The average age is 45.8 years old. Nearly half the sample (49.4%) is male and 64.8% of resopndents are married. The majority (73.2%) are employed, with the modal household income is over \$80,000. Although nearly a quarter of respondents report a household income of \$50,000 - \$79,999. Welfare is reported as the main source of income for a minority (2.6%) of households while home ownership is reported by a majority (76.6%). More than half the sample (53.4%) has graduated from college, and 22.9% have less than a high school education. The average height in the sample is 1.70 meters, 81.1% are Canadian born, 23.3% of households report having kids under the age of 12. A little over 3 out of 5 (61.9%) respondents report a sense of community belonging.

### 6.2 Exogeneity Tests - Bivariate Probit

The bivariate probit allows for the correlation between the error terms ($u_{pi}$ and $u_{hi}$) to be non-zero: $\text{corr}(u_{pi}, u_{hi}) = \rho$. If $\rho = 0$, then the bivariate probit is equivalent to two independent probit models. We can interpret this as saying the factors affecting the probability of participating in physical activity ($y_{pi}$) and the factors affecting the probability of a health outcome ($y_{hi}$) are exogenous. However, if $\rho \neq 0$, then we interpret this as evidence of unobservable factors that influence the probability of participating in physical activity ($y_{pi}$) also influence the probability of a health outcome ($y_{hi}$). Thus, a bivariate probit model is required for consistent parameter estimate.

We use two different tests for exogeneity. First, we use an asymptotic z-text for the significance of the estimated $\rho$ from each model. Second, we use an likelihood ratio (LR) test to compare the log-likelihood of the bivariate probit model with the sum of the log-likelihoods of the two single equation probit models.

Table 5 reports the estimated correlation between the error terms ($\hat{\rho}$), the z-score and significance level for the z-test, and the $\chi^2$ statistic and significance level for the LR test. As shown in columns (1), (4), and (7), all estimated correlations are positive (with the exception of $\hat{\rho}$ for asthma in column (1)). We interpret this to say that the correlation between the errors in the physical activity equation and the health outcome equation is positive which suggests unobservable factors that increase the probability of physical activity also increase the probability of a health outcome.

The z-test and LR-test, as shown in columns (2), (3), (5), (6), (8) and (9), suggest all estimated correlations are statistically significant from zero at the 5% level, with the exception of high-blood pressure in column (8) and (9) which is only significant at the 10% level and for heart disease and asthma in columns (2) and (3) which are not statistically different from zero at the 10% level. This suggests that ignoring this correlation and simply using two independent probit models for $y_{pi}$ and $y_{hi}$ would estimates with an upward bias.

### 6.3 Partial Marginal Effect of Physical Activity on Health Outcomes - Bivariate Probit

The relationship between the level of participation in physical activity and health outcomes is the primary focus of this investigation. Instead of reporting full regression results for each of the different levels of participation in physical activity and health outcome in the body of the paper, we report the estimated partial marginal effects of participation in physical activity on health outcomes in Table 6.[3]

For each health outcome, Table 6 reports the expected probability of participating in physical activity and having the health outcome ($E[Pr(y_{hi} = 1, y_{pi} = 1)]$) and the partial marginal effect of a change in physical activity status from 0 to 1. This is approximately equivalent to the the difference between $E[Pr(y_{hi} = 1, y_{pi} = 0)]$ and $E[Pr(y_{hi} = 1, y_{pi} = 1)]$. To get a sense of the relative magnitude of the partial marginal effect we report the percentage change in $E[Pr(y_{hi} = 1, y_{pi} = 0)]$ to $E[Pr(y_{hi} = 1, y_{pi} = 1)]$ in square brackets.[4]

Overall, there is a clear effect of participation in physical activity and health outcomes. Participation in physical activity (daily, active, or moderately active) reduces the probability of having one of the six negative health outcomes. Moderately active participation reduces the probability of a negative health outcome (measured in percentage points) more than active participation. This finding suggests that there are diminishing returns to physical activity in reducing the probability

[3] A full set of parameter estimates from all models is reported in Appendix Tables A.2-A.13. Overall, the estimated parameters of the reduced form equation for participation in physical activity are similar to other results in the literature (Humphreys and Ruseski (2007, 2009)).

[4] For example, in Table 6, in column (1), people with fair or poor self reported health, $E[Pr(y_{hi} = 1, y_{pi} = 1)] = 0.144$. The partial marginal effect of a change in physical activity status from 0 to 1 is equal to -0.182. We can infer that $E[Pr(y_{hi} = 1, y_{pi} = 0)] \sim E[Pr(y_{hi} = 1, y_{pi} = 1)] + 0.182 = 0.326$. The percentage change is given by: $(0.144)/(E[Pr(y_{hi} = 1, y_{pi} = 0)]) = (-0.182)/(0.326) = -55.7\%$.

of chronic disease.

The effects appear largest for people having fair or poor self-reported health. The marginal impact of participation in physical activity declines from 18.2 percentage points for moderate to 20.4 percentage points for active. However, the marginal impact of daily participation in physical activity is highest at 24.6 percentage points. These large percentage point reductions also have large relatively percentage reductions (54.5% to 60.4%) in the probability of having fair or poor self-reported health.

For the five specific chronic conditions, the effects are slightly smaller. For diabetes, the marginal impact of participation in physical activity declines from 12.9 percentage points for moderately active participation to 8.8 percentage points for active participation to 2.5 percentage points for daily participation. However, these modest percentage point reductions translate into relatively large percentage reductions (46.6% to 59.1%) in the joint probability of diabetes and participation in physical activity.

Similar patterns emerge for high blood pressure, heart disease, arthritis, and asthma. The only chronic conditions for which this pattern does not hold is heart disease and asthma where active participation is not statistically significant in reducing the probability of having heart disease or asthma.

## 7 Discussion

We use the Grossman health production framework to examine the influence of participation in physical activity on health outcomes. We focus on participation in physical activity because sedentary lifestyles have been recognized as a modifiable risk factor for several chronic diseases like diabetes, heart disease, stroke, arthritis and some types of cancer. However, questions remain as to the frequency and intensity of physical activity needed to reduce the incidence of disease. To explore the effect of different levels of participation in physical activity on health outcomes, we estimate the structural parameters of a series of health production functions together with the reduced form parameters for various physical activity equations specified as recursive bivariate probit models using data from the 2005 CCHS. The models are estimated using maximum likelihood for a bivariate probit model with discrete indicators of the level of participation in physical activity and health outcomes.

We use three derived binary variables to examine the effects of different levels of participation in physical activity on health outcomes. The first two, an indicator for individuals who are active participants and an indicator for individuals who are moderately active participants, are based on the average daily energy expended on leisure time physical activity, based on the CCHS Physical Activity Index. The third measure is an indicator for individuals who participated in leisure time physical activity daily. We focus on four health outcomes that have been linked with physical activity in the epidemiological literature: arthritis, high blood pressure, diabetes, and heart disease. We also examine asthma as a fifth health outcome and fair or poor self-reported health. Each health outcome is measured as a binary variable taking on the value of 1 if the individual reported having any of these conditions or being in fair or poor health and zero otherwise. In keeping with Grossman's health production framework, socioeconomic and individual characteristics are included as explanatory variables in the analysis.

We find evidence of a clear effect of participation in physical activity on health outcomes. Participation in physical activity at any level reduces the probability of reporting being in fair or poor health and of having diabetes, high blood pressure and arthritis. Moderate or daily activity reduces the probability of having heart disease and asthma; however, being an active participant does not have a significant effect on reducing the probability of having these conditions. We find that moderate participation in physical activity has the largest marginal impact on reducing the probability of negative health outcomes. These results suggest that there are diminishing marginal returns to participation in physical activity. Moderate participation appears to be sufficient to generate tangible health benefits. Our results are consistent with previous studies examining the relationship between health-related behaviors and health that found a positive relationship between physical activity and health (Kenkel (1995); Contoyannis and Jones (2004); Rascuite and Downward (2010)). Our results add to these findings by examining the contribution of different frequencies and intensities of physical activity to health.

Table 1: Summary Statistics - Physical Activity and Health Outcomes Variables

| | **n** | **Mean** |
|---|---|---|
| | (1) | (2) |
| **Physicial Activity Measures** ($y_p$) | | |
| Daily Physical Activiy | 111,047 | 36.2% |
| Physical Activity Index "Active" | 111,047 | 24.5% |
| Physical Activity Index "Moderate" | 111,047 | 25.6% |
| **Health Outcomes** ($y_h$) | | |
| Has Diabetes | 111,739 | 5.2% |
| Has High Blood Pressure | 111,746 | 16.4% |
| Has Heart Disease | 111,736 | 5.2% |
| Has Arthritis | 111,750 | 18.1% |
| Has Asthma | 111,752 | 8.1% |
| Has Ulcers | 111,738 | 3.4% |
| Fair or Poor Self-Reported Health | 111,656 | 11.5% |

Table 2: Number and Proportion of Respondents with Daily Participation by Active Participation and Moderately Active Participation

| Intensity of Participation (Physical Activity Index) | Daily Participation No | Daily Participation Yes | Total |
|---|---|---|---|
| | (1) | (2) | (3) |
| Active (Yes) | 1,698 | 25,507 | 27,205 |
| | [6.2%] | [93.8%] | |
| Moderately Active (Yes) | 16,193 | 12,247 | 28,441 |
| | [56.9%] | [43.1%] | |

Table 3: Proportion of Respondents with given health outcome ($y_{hi}$), by Physical Activity ($y_{pi}$)

| Participation in Physical Activity: | Active | | | Moderate | | | Daily | | |
|---|---|---|---|---|---|---|---|---|---|
| | No | Yes | Total | No | Yes | Total | No | Yes | Total |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Fair or Poor Self Reported Health | 10,922 | 1,520 | 12,441 | 10,109 | 2,333 | 12,441 | 9,257 | 3,184 | 12,441 |
| | [87.8%] | [12.2%] | | [81.3%] | [18.7%] | | [74.4%] | [25.6%] | |
| Diabetes | 4,761 | 944 | 5,705 | 4,464 | 1,241 | 5,705 | 3,825 | 1,880 | 5,705 |
| | [83.5%] | [16.5%] | | [78.3%] | [21.7%] | | [67.0%] | [33.0%] | |
| High Blood Pressure | 14,862 | 3,113 | 17,976 | 13,592 | 4,384 | 17,976 | 12,147 | 5,828 | 17,976 |
| | [82.7%] | [17.3%] | | [75.6%] | [24.4%] | | [67.6%] | [32.4%] | |
| Heart Disease | 4,648 | 926 | 5,574 | 4,299 | 1,275 | 5,574 | 3,798 | 1,776 | 5,574 |
| | [83.4%] | [16.6%] | | [77.1%] | [22.9%] | | [68.1%] | [31.9%] | |
| Arthritis | 16,154 | 3,758 | 19,912 | 15,124 | 4,788 | 19,912 | 13,109 | 6,803 | 19,912 |
| | [81.1%] | [18.9%] | | [76.0%] | [24.0%] | | [65.8%] | [34.2%] | |
| Asthma | 6,850 | 2,175 | 9,025 | 6,766 | 2,259 | 9,025 | 5,749 | 3,276 | 9,025 |
| | [75.9%] | [24.1%] | | [75.0%] | [25.0%] | | [63.7%] | [36.3%] | |
| Ulcers | 2,979 | 750 | 3,729 | 2,862 | 867 | 3,729 | 2,516 | 1,213 | 3,729 |
| | [79.9%] | [20.1%] | | [76.7%] | [23.3%] | | [67.5%] | [32.5%] | |

Table 4: Summary Statistics - Independent Variables

| | **Mean** | **Min.** | **Max.** |
|---|---|---|---|
| | (1) | (2) | (3) |
| Age | 45.8 | 18.5 | 85 |
| Male | 0.488 | 0 | 1 |
| Married | 0.648 | 0 | 1 |
| Widowed / Divorced | 0.125 | 0 | 1 |
| Single | 0.226 | 0 | 1 |
| Martial Status - Not Stated | 0.001 | 0 | 1 |
| Employed | 0.732 | 0 | 1 |
| Income ($0 - $14,999) | 0.049 | 0 | 1 |
| Income ($15,000 - $29,999) | 0.112 | 0 | 1 |
| Income ($30,000 - $49,999) | 0.175 | 0 | 1 |
| Income ($50,000 - $79,999) | 0.238 | 0 | 1 |
| Income ($80,000 or more) | 0.303 | 0 | 1 |
| Income - Not Stated | 0.122 | 0 | 1 |
| Welfare Main Source of Income | 0.026 | 0 | 1 |
| Owns Home | 0.766 | 0 | 1 |
| Less than High School | 0.165 | 0 | 1 |
| High School | 0.166 | 0 | 1 |
| Some College | 0.092 | 0 | 1 |
| College Graduate | 0.573 | 0 | 1 |
| Education - Not Stated | 0.004 | 0 | 1 |
| Height (m) | 1.70 | 1.40 | 1.96 |
| Kids (less than 12 years old) | 0.233 | 0 | 1 |
| Canadian Born | 0.811 | 0 | 1 |
| Nfld. | 0.018 | 0 | 1 |
| PEI | 0.005 | 0 | 1 |
| Nova Scotia | 0.031 | 0 | 1 |
| New Brunswick | 0.025 | 0 | 1 |
| Quebec | 0.243 | 0 | 1 |
| Ontario | 0.378 | 0 | 1 |
| Manitoba | 0.035 | 0 | 1 |
| Saskatchewan | 0.030 | 0 | 1 |
| Alberta | 0.100 | 0 | 1 |
| British Columbia | 0.133 | 0 | 1 |
| Territories | 0.003 | 0 | 1 |
| Sense of Community Belonging | 0.619 | 0 | 1 |

Table 5: Exogeneity Test - $H_0$: $\rho = 0$, Bivariate Probit

| Participation in Physical Activity: | Active | | | Moderate | | | Daily | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\hat{\rho}$ | z-test | LR-test | $\hat{\rho}$ | z-test | LR-test | $\hat{\rho}$ | z-test | LR-test |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Fair or Poor Self-Reported Health | 0.882 | 32.30 *** | 1043.08 *** | 0.919 | 33.80 *** | 1142.40 *** | 0.836 | 32.54 *** | 1058.59 *** |
| Has Diabetes | 0.729 | 5.25 *** | 27.52 *** | 0.831 | 12.54 *** | 157.13 *** | 0.267 | 2.09 ** | 4.35 ** |
| Has High Blood Pressure | 0.814 | 7.26 *** | 52.69 *** | 0.909 | 18.77 *** | 352.13 *** | 0.196 | 1.83 * | 3.35 * |
| Has Heart Disease | 0.211 | 1.52 | 2.31 | 0.788 | 13.91 *** | 193.42 *** | 0.569 | 2.99 *** | 8.96 *** |
| Has Arthritis | 0.641 | 2.86 *** | 8.20 *** | 0.880 | 16.96 *** | 287.71 *** | 0.416 | 2.38 ** | 5.65 ** |
| Has Asthma | -0.002 | -0.01 | 0.00 | 0.686 | 3.78 *** | 14.29 *** | 0.235 | 2.44 ** | 5.95 ** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Partial Marginal Effects at the Mean - Physical Activity on Health Outcomes

| | Fair or Poor Self-Reported Health | | | Diabetes | | | High Blood Pressure | | |
|---|---|---|---|---|---|---|---|---|---|
| | $E[Pr]$ | Partial MFX | | $E[Pr]$ | Partial MFX | | $E[Pr]$ | Partial MFX | |
| Participation | (1) | (2) | | (3) | (4) | | (5) | (6) | |
| Active | 0.144 | -0.182 | *** | 0.063 | -0.088 | *** | 0.146 | -0.157 | *** |
| | | [-55.7%] | | | [-58.2%] | | | [-51.9%] | |
| Moderately Active | 0.170 | -0.204 | *** | 0.089 | -0.129 | *** | 0.187 | -0.194 | *** |
| | | [-54.5%] | | | [-59.1%] | | | [-50.9%] | |
| Daily | 0.161 | -0.246 | *** | 0.029 | -0.025 | * | 0.075 | -0.041 | ** |
| | | [-60.4%] | | | [-46.6%] | | | [-35.1%] | |

| | Heart Disease | | | Arthritis | | | Asthma | | |
|---|---|---|---|---|---|---|---|---|---|
| Participation | $E[Pr]$ | Partial MFX | | $E[Pr]$ | Partial MFX | | $E[Pr]$ | Partial MFX | |
| | (7) | (8) | | (9) | (10) | | (11) | (12) | |
| Active | 0.014 | -0.012 | | 0.119 | -0.111 | *** | 0.019 | -0.001 | |
| | | [-45.3%] | | | [-48.3%] | | | [-5.4%] | |
| Moderately Active | 0.068 | -0.101 | *** | 0.188 | -0.186 | *** | 0.085 | -0.099 | *** |
| | | [-59.7%] | | | [-49.7%] | | | [-53.7%] | |
| Daily | 0.044 | -0.070 | ** | 0.117 | -0.093 | ** | 0.045 | -0.028 | ** |
| | | [-61.3%] | | | [-44.3%] | | | [-38.6%] | |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

$E[Pr] = E[Pr(y_{hi} = 1, y_{pi} = 1)$

Partial Marginal Effect is the change in $Pr(y_{hi} = 1, y_{pi} = 1)$ from changing $y_{hi}$ from 0 to 1

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# A Appendix

Table A.1: Comparison of the CCHS 3.1 Full Sample and the CCHS 3.1 Analysis Sample

| | CCHS 3.1 (Full Sample) | | CCHS 3.1 (Analysis Sample) | | Ratio of Means | |
|---|---|---|---|---|---|---|
| | **n** | **Mean** | **n** | **Mean** | | |
| | (1) | (2) | (3) | (4) | (3)/(1) | (4)/(2) |
| Age | 132,221 | 42.966 | 111,770 | 45.809 | 0.85 | 1.07 |
| Male | 132,221 | 0.493 | 111,770 | 0.488 | 0.85 | 0.99 |
| Married | 132,221 | 0.588 | 111,770 | 0.648 | 0.85 | 1.10 |
| Widowed / Divorced | 132,221 | 0.113 | 111,770 | 0.125 | 0.85 | 1.10 |
| Single | 132,221 | 0.298 | 111,770 | 0.226 | 0.85 | 0.76 |
| Martial Status - Not Stated | 132,221 | 0.001 | 111,770 | 0.001 | 0.85 | 1.21 |
| Employed | 130,969 | 0.692 | 111,770 | 0.732 | 0.85 | 1.06 |
| Income ($0 - $14,999) | 132,221 | 0.047 | 111,770 | 0.049 | 0.85 | 1.04 |
| Income ($15,000 - $29,999) | 132,221 | 0.108 | 111,770 | 0.112 | 0.85 | 1.04 |
| Income ($30,000 - $49,999) | 132,221 | 0.168 | 111,770 | 0.175 | 0.85 | 1.04 |
| Income ($50,000 - $79,999) | 132,221 | 0.229 | 111,770 | 0.238 | 0.85 | 1.04 |
| Income ($80,000 or more) | 132,221 | 0.290 | 111,770 | 0.303 | 0.85 | 1.04 |
| Income - Not Stated | 132,221 | 0.158 | 111,770 | 0.122 | 0.85 | 0.77 |
| Welfare Main Source of Income | 132,221 | 0.027 | 111,770 | 0.026 | 0.85 | 0.95 |
| Owns Home | 128,718 | 0.768 | 111,770 | 0.766 | 0.87 | 1.00 |
| Less than High School | 132,221 | 0.233 | 111,770 | 0.165 | 0.85 | 0.71 |
| High School | 132,221 | 0.147 | 111,770 | 0.166 | 0.85 | 1.13 |
| Some College | 132,221 | 0.084 | 111,770 | 0.092 | 0.85 | 1.09 |
| College Graduate | 132,221 | 0.506 | 111,770 | 0.573 | 0.85 | 1.13 |
| Education - Not Stated | 132,221 | 0.029 | 111,770 | 0.004 | 0.85 | 0.14 |
| Height (m) | 131,110 | 1.693 | 111,770 | 1.697 | 0.85 | 1.00 |
| Kids (less than 12 years old) | 132,221 | 0.246 | 111,770 | 0.233 | 0.85 | 0.95 |
| Canadian Born | 125,991 | 0.819 | 111,770 | 0.811 | 0.89 | 0.99 |
| Nfld. | 132,221 | 0.017 | 111,770 | 0.018 | 0.85 | 1.09 |
| PEI | 132,221 | 0.004 | 111,770 | 0.005 | 0.85 | 1.15 |
| Nova Scotia | 132,221 | 0.029 | 111,770 | 0.031 | 0.85 | 1.06 |
| New Brunswick | 132,221 | 0.024 | 111,770 | 0.025 | 0.85 | 1.06 |
| Quebec | 132,221 | 0.238 | 111,770 | 0.243 | 0.85 | 1.02 |
| Ontario | 132,221 | 0.390 | 111,770 | 0.378 | 0.85 | 0.97 |
| Manitoba | 132,221 | 0.034 | 111,770 | 0.035 | 0.85 | 1.02 |
| Saskatchewan | 132,221 | 0.029 | 111,770 | 0.030 | 0.85 | 1.03 |
| Alberta | 132,221 | 0.099 | 111,770 | 0.100 | 0.85 | 1.01 |
| British Columbia | 132,221 | 0.133 | 111,770 | 0.133 | 0.85 | 1.00 |
| Territories | 132,221 | 0.003 | 111,770 | 0.003 | 0.85 | 1.06 |
| Sense of Community Belonging | 132,221 | 0.623 | 111,770 | 0.619 | 0.85 | 0.99 |

Table A.2: Coefficient Estimates - Bivariate Probit, Structural Health Equation, Self-Reported Health is Fair or Poor

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.001 | *** | 0.004 | *** | 0.002 | *** |
| Male | 0.188 | *** | 0.089 | *** | 0.106 | *** |
| Widowed / Separated / Divorced | 0.002 | | -0.034 | *** | -0.027 | ** |
| Single | 0.009 | | -0.07 | *** | -0.023 | * |
| Martial Status - Not Stated | 0.144 | | 0.029 | | 0.129 | |
| Employed | -0.429 | *** | -0.303 | *** | -0.444 | *** |
| Income ($15,000 - $29,999) | -0.11 | *** | -0.12 | *** | -0.109 | *** |
| Income ($30,000 - $49,999) | -0.222 | *** | -0.199 | *** | -0.225 | *** |
| Income ($50,000 - $79,999) | -0.247 | *** | -0.22 | *** | -0.269 | *** |
| Income ($80,000 or more) | -0.275 | *** | -0.284 | *** | -0.334 | *** |
| Houshold Income - Not Stated | -0.124 | *** | -0.187 | *** | -0.143 | *** |
| Welfare main source of income | 0.341 | *** | 0.309 | *** | 0.392 | *** |
| Owns Home | -0.026 | ** | -0.054 | *** | -0.052 | *** |
| High School | -0.126 | *** | -0.114 | *** | -0.111 | *** |
| Some College | -0.08 | *** | -0.072 | *** | -0.061 | *** |
| College Graduate | -0.089 | *** | -0.088 | *** | -0.078 | *** |
| Education - Not Stated | 0.032 | | -0.135 | ** | 0.003 | |
| Height | -0.179 | *** | -0.395 | *** | -0.277 | *** |
| Kids | -0.209 | *** | -0.136 | *** | -0.205 | *** |
| Canadian Born | 0.066 | *** | 0.067 | *** | 0.061 | *** |
| PA Index - Active | -1.700 | *** | | | | |
| PA Index - Modertly Active | | | -1.566 | *** | | |
| Daily Physical Activity | | | | | -1.555 | *** |
| Intercept | 0.082 | | 0.332 | *** | 0.311 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.3: Coefficient Estimates - Bivariate Probit, Reduced Form Physical Activity Equation, Self-Reported Health is Fair or Poor

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.011 | *** | -0.001 | *** | -0.005 | *** |
| Male | 0.067 | *** | -0.066 | *** | -0.082 | *** |
| Widowed / Separated / Divorced | 0.029 | ** | -0.027 | ** | -0.001 | |
| Single | 0.102 | *** | -0.027 | ** | 0.072 | *** |
| Martial Status - Not Stated | 0.114 | | -0.1 | | 0.081 | |
| Employed | -0.193 | *** | -0.036 | *** | -0.195 | *** |
| Income ($15,000 - $29,999) | 0.067 | *** | 0.016 | | 0.051 | *** |
| Income ($30,000 - $49,999) | 0.073 | *** | 0.059 | *** | 0.052 | *** |
| Income ($50,000 - $79,999) | 0.114 | *** | 0.094 | *** | 0.074 | *** |
| Income ($80,000 or more) | 0.22 | *** | 0.128 | *** | 0.143 | *** |
| Houshold Income - Not Stated | 0.141 | *** | -0.001 | | 0.093 | *** |
| Welfare main source of income | 0.013 | | -0.022 | | 0.077 | *** |
| Owns Home | 0.094 | *** | 0.039 | *** | 0.055 | *** |
| High School | 0.125 | *** | 0.101 | *** | 0.129 | *** |
| Some College | 0.149 | *** | 0.12 | *** | 0.156 | *** |
| College Graduate | 0.217 | *** | 0.166 | *** | 0.209 | *** |
| Education - Not Stated | 0.182 | *** | -0.156 | ** | 0.109 | * |
| Height | 0.605 | *** | 0.143 | ** | 0.465 | *** |
| Kids | -0.156 | *** | -0.052 | *** | -0.129 | *** |
| Canadian Born | 0.032 | ** | 0.044 | *** | 0.025 | ** |
| Strong Sense of Community | 0.25 | *** | 0.144 | *** | 0.252 | *** |
| $\rho$ | 0.882 | *** | 0.920 | *** | 0.836 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: Coefficient Estimates - Bivariate Probit, Structural Health Equation, Incidence of Diabetes

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | 0.01 | *** | 0.012 | *** | 0.016 | *** |
| Male | 0.218 | *** | 0.127 | *** | 0.214 | *** |
| Widowed / Separated / Divorced | -0.048 | *** | -0.07 | *** | -0.076 | *** |
| Single | -0.047 | ** | -0.1 | *** | -0.109 | *** |
| Martial Status - Not Stated | -0.13 | | -0.209 | | -0.18 | |
| Employed | -0.242 | *** | -0.152 | *** | -0.222 | *** |
| Income ($15,000 - $29,999) | -0.039 | * | -0.047 | ** | -0.069 | *** |
| Income ($30,000 - $49,999) | -0.07 | *** | -0.055 | ** | -0.111 | *** |
| Income ($50,000 - $79,999) | -0.072 | *** | -0.053 | ** | -0.134 | *** |
| Income ($80,000 or more) | -0.119 | *** | -0.122 | *** | -0.245 | *** |
| Houshold Income - Not Stated | -0.097 | *** | -0.141 | *** | -0.169 | *** |
| Welfare main source of income | 0.139 | *** | 0.11 | *** | 0.189 | *** |
| Owns Home | -0.027 | | -0.04 | *** | -0.082 | *** |
| High School | -0.027 | | -0.017 | | -0.072 | *** |
| Some College | 0.008 | | 0.016 | | -0.038 | |
| College Graduate | 0.038 | * | 0.04 | *** | -0.028 | |
| Education - Not Stated | 0.042 | | -0.102 | | -0.012 | |
| Height | -0.192 | * | -0.337 | *** | -0.49 | *** |
| Kids | -0.245 | *** | -0.181 | *** | -0.243 | *** |
| Canadian Born | 0.059 | *** | 0.062 | *** | 0.053 | *** |
| PA Index - Active | -1.286 | *** | | | | |
| PA Index - Modertly Active | | | -1.378 | *** | | |
| Daily Physical Activity | | | | | -0.500 | *** |
| Intercept | -1.105 | *** | -0.777 | *** | -1.062 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.5: Coefficient Estimates - Bivariate Probit, Reduced Form Physical Activity Equation, Incidence of Diabetes

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.011 | *** | -0.001 | *** | -0.005 | *** |
| Male | 0.06 | *** | -0.076 | *** | -0.088 | *** |
| Widowed / Separated / Divorced | 0.032 | ** | -0.028 | ** | 0 | |
| Single | 0.105 | *** | -0.024 | ** | 0.076 | *** |
| Martial Status - Not Stated | 0.11 | | -0.107 | | 0.076 | |
| Employed | -0.191 | *** | -0.028 | ** | -0.197 | *** |
| Income ($15,000 - $29,999) | 0.073 | *** | 0.026 | | 0.052 | *** |
| Income ($30,000 - $49,999) | 0.082 | *** | 0.069 | *** | 0.054 | *** |
| Income ($50,000 - $79,999) | 0.125 | *** | 0.107 | *** | 0.077 | *** |
| Income ($80,000 or more) | 0.23 | *** | 0.141 | *** | 0.151 | *** |
| Houshold Income - Not Stated | 0.146 | *** | 0 | | 0.093 | *** |
| Welfare main source of income | 0.015 | | -0.03 | | 0.076 | *** |
| Owns Home | 0.107 | *** | 0.05 | *** | 0.06 | *** |
| High School | 0.128 | *** | 0.104 | *** | 0.129 | *** |
| Some College | 0.15 | *** | 0.122 | *** | 0.156 | *** |
| College Graduate | 0.215 | *** | 0.165 | *** | 0.208 | *** |
| Education - Not Stated | 0.162 | ** | -0.159 | ** | 0.09 | |
| Height | 0.625 | *** | 0.167 | *** | 0.474 | *** |
| Kids | -0.151 | *** | -0.042 | *** | -0.127 | *** |
| Canadian Born | 0.035 | *** | 0.043 | *** | 0.025 | ** |
| Strong Sense of Community | 0.206 | *** | 0.068 | *** | 0.224 | *** |
| $\rho$ | 0.729 | *** | 0.831 | *** | 0.267 | ** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.6: Coefficient Estimates - Bivariate Probit, Structural Health Equation, Incidence of Heart Disease

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | 0.025 | *** | 0.02 | *** | 0.022 | *** |
| Male | 0.316 | *** | 0.198 | *** | 0.244 | *** |
| Widowed / Separated / Divorced | -0.065 | *** | -0.066 | *** | -0.065 | *** |
| Single | -0.146 | *** | -0.13 | *** | -0.117 | *** |
| Martial Status - Not Stated | -0.499 | * | -0.425 | * | -0.429 | |
| Employed | -0.303 | *** | -0.226 | *** | -0.325 | *** |
| Income ($15,000 - $29,999) | -0.099 | *** | -0.071 | *** | -0.076 | *** |
| Income ($30,000 - $49,999) | -0.139 | *** | -0.084 | *** | -0.113 | *** |
| Income ($50,000 - $79,999) | -0.175 | *** | -0.094 | *** | -0.142 | *** |
| Income ($80,000 or more) | -0.24 | *** | -0.138 | *** | -0.187 | *** |
| Houshold Income - Not Stated | -0.151 | *** | -0.133 | *** | -0.119 | *** |
| Welfare main source of income | 0.196 | *** | 0.131 | *** | 0.201 | *** |
| Owns Home | -0.094 | *** | -0.058 | *** | -0.071 | *** |
| High School | -0.053 | ** | -0.003 | | -0.011 | |
| Some College | 0.012 | | 0.056 | ** | 0.055 | * |
| College Graduate | 0.005 | | 0.063 | *** | 0.06 | ** |
| Education - Not Stated | -0.11 | | -0.176 | ** | -0.087 | |
| Height | -0.282 | ** | -0.198 | ** | -0.144 | |
| Kids | -0.137 | *** | -0.104 | *** | -0.151 | *** |
| Canadian Born | 0.085 | *** | 0.088 | *** | 0.085 | *** |
| PA Index - Active | -0.504 | ** | | | | |
| PA Index - Modertly Active | | | -1.300 | *** | | |
| Daily Physical Activity | | | | | -0.997 | *** |
| Intercept | -2.183 | *** | -1.636 | *** | -1.962 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.7: Coefficient Estimates - Bivariate Probit, Reduced Form Physical Activity Equation, Incidence of Heart Disease

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.011 | *** | -0.001 | *** | -0.005 | *** |
| Male | 0.061 | *** | -0.076 | *** | -0.087 | *** |
| Widowed / Separated / Divorced | 0.033 | *** | -0.027 | ** | 0 | |
| Single | 0.11 | *** | -0.023 | * | 0.075 | *** |
| Martial Status - Not Stated | 0.112 | | -0.111 | | 0.071 | |
| Employed | -0.191 | *** | -0.026 | ** | -0.196 | *** |
| Income ($15,000 - $29,999) | 0.071 | *** | 0.022 | | 0.051 | *** |
| Income ($30,000 - $49,999) | 0.081 | *** | 0.067 | *** | 0.053 | *** |
| Income ($50,000 - $79,999) | 0.123 | *** | 0.104 | *** | 0.076 | *** |
| Income ($80,000 or more) | 0.23 | *** | 0.139 | *** | 0.15 | *** |
| Houshold Income - Not Stated | 0.144 | *** | -0.002 | | 0.092 | *** |
| Welfare main source of income | 0.014 | | -0.03 | | 0.075 | *** |
| Owns Home | 0.106 | *** | 0.049 | *** | 0.06 | *** |
| High School | 0.128 | *** | 0.104 | *** | 0.13 | *** |
| Some College | 0.15 | *** | 0.122 | *** | 0.157 | *** |
| College Graduate | 0.215 | *** | 0.165 | *** | 0.208 | *** |
| Education - Not Stated | 0.163 | ** | -0.161 | ** | 0.091 | |
| Height | 0.626 | *** | 0.163 | *** | 0.474 | *** |
| Kids | -0.15 | *** | -0.042 | *** | -0.127 | *** |
| Canadian Born | 0.034 | *** | 0.044 | *** | 0.025 | ** |
| Strong Sense of Community | 0.228 | *** | 0.077 | *** | 0.22 | *** |
| $\rho$ | 0.882 | | 0.920 | *** | 0.836 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.8: Coefficient Estiamtes - Bivariate Probit, Structural Health Equation, Incidence of High Blood Pressure

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | 0.02 | *** | 0.021 | *** | 0.03 | *** |
| Male | 0.051 | *** | -0.024 | ** | 0.02 | |
| Widowed / Separated / Divorced | -0.018 | | -0.045 | *** | -0.053 | *** |
| Single | -0.034 | * | -0.087 | *** | -0.12 | *** |
| Martial Status - Not Stated | 0.086 | | -0.033 | | 0.055 | |
| Employed | -0.177 | *** | -0.09 | *** | -0.127 | *** |
| Income ($15,000 - $29,999) | -0.007 | | -0.019 | | -0.034 | * |
| Income ($30,000 - $49,999) | 0.008 | | 0.016 | | -0.015 | |
| Income ($50,000 - $79,999) | 0.018 | | 0.027 | | -0.031 | |
| Income ($80,000 or more) | 0.036 | | 0.014 | | -0.078 | *** |
| Houshold Income - Not Stated | -0.047 | ** | -0.096 | *** | -0.12 | *** |
| Welfare main source of income | 0.152 | *** | 0.116 | *** | 0.235 | *** |
| Owns Home | 0.065 | *** | 0.039 | *** | 0.027 | ** |
| High School | -0.003 | | 0.005 | | -0.045 | ** |
| Some College | 0.006 | | 0.014 | | -0.047 | ** |
| College Graduate | 0.019 | | 0.022 | * | -0.06 | *** |
| Education - Not Stated | 0.004 | | -0.125 | ** | -0.059 | |
| Height | -0.116 | | -0.27 | *** | -0.473 | *** |
| Kids | -0.236 | *** | -0.157 | *** | -0.247 | *** |
| Canadian Born | 0.037 | *** | 0.04 | *** | 0.021 | |
| PA Index - Active | -1.426 | *** | | | | |
| PA Index - Modertly Active | | | -1.428 | *** | | |
| Daily Physical Activity | | | | | -0.407 | ** |
| Intercept | -1.193 | *** | -0.837 | *** | -1.257 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.9: Coefficient Estimates - Bivariate Probit, Reduced Form Physical Activity Equation, Incidence of High Blood Pressure

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.011 | *** | -0.001 | *** | -0.005 | *** |
| Male | 0.049 | *** | -0.084 | *** | -0.088 | *** |
| Widowed / Separated / Divorced | 0.034 | *** | -0.025 | ** | 0.001 | |
| Single | 0.101 | *** | -0.029 | ** | 0.076 | *** |
| Martial Status - Not Stated | 0.096 | | -0.106 | | 0.076 | |
| Employed | -0.192 | *** | -0.027 | ** | -0.196 | *** |
| Income ($15,000 - $29,999) | 0.062 | *** | 0.025 | | 0.051 | *** |
| Income ($30,000 - $49,999) | 0.073 | *** | 0.063 | *** | 0.054 | *** |
| Income ($50,000 - $79,999) | 0.113 | *** | 0.102 | *** | 0.077 | *** |
| Income ($80,000 or more) | 0.219 | *** | 0.136 | *** | 0.15 | *** |
| Houshold Income - Not Stated | 0.134 | *** | -0.004 | | 0.092 | *** |
| Welfare main source of income | 0.009 | | -0.029 | | 0.075 | *** |
| Owns Home | 0.113 | *** | 0.053 | *** | 0.06 | *** |
| High School | 0.122 | *** | 0.1 | *** | 0.129 | *** |
| Some College | 0.141 | *** | 0.12 | *** | 0.156 | *** |
| College Graduate | 0.209 | *** | 0.162 | *** | 0.208 | *** |
| Education - Not Stated | 0.158 | ** | -0.133 | ** | 0.092 | |
| Height | 0.615 | *** | 0.152 | ** | 0.475 | *** |
| Kids | -0.154 | *** | -0.047 | *** | -0.127 | *** |
| Canadian Born | 0.033 | ** | 0.044 | *** | 0.025 | ** |
| Strong Sense of Community | 0.182 | *** | 0.055 | *** | 0.224 | *** |
| $\rho$ | 0.882 | *** | 0.920 | *** | 0.836 | * |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.10: Coefficient Estiamtes - Bivariate Probit, Structural Health Equation, Incidence of Arthritis

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | 0.022 | *** | 0.02 | *** | 0.026 | *** |
| Male | -0.232 | *** | -0.247 | *** | -0.294 | *** |
| Widowed / Separated / Divorced | -0.048 | *** | -0.06 | *** | -0.071 | *** |
| Single | -0.112 | *** | -0.132 | *** | -0.154 | *** |
| Martial Status - Not Stated | 0.003 | | -0.09 | | -0.02 | |
| Employed | -0.188 | *** | -0.114 | *** | -0.178 | *** |
| Income ($15,000 - $29,999) | -0.02 | | -0.024 | | -0.029 | |
| Income ($30,000 - $49,999) | -0.08 | *** | -0.053 | *** | -0.093 | *** |
| Income ($50,000 - $79,999) | -0.112 | *** | -0.069 | *** | -0.142 | *** |
| Income ($80,000 or more) | -0.156 | *** | -0.117 | *** | -0.219 | *** |
| Houshold Income - Not Stated | -0.107 | *** | -0.128 | *** | -0.14 | *** |
| Welfare main source of income | 0.346 | *** | 0.262 | *** | 0.405 | *** |
| Owns Home | 0.014 | | 0.006 | | -0.008 | |
| High School | -0.025 | | -0.002 | | -0.031 | |
| Some College | 0.022 | | 0.038 | ** | 0.017 | |
| College Graduate | -0.004 | | 0.021 | * | -0.021 | |
| Education - Not Stated | -0.017 | | -0.124 | ** | -0.046 | |
| Height | 0.183 | * | 0.053 | | 0.075 | |
| Kids | -0.258 | *** | -0.179 | *** | -0.26 | *** |
| Canadian Born | 0.138 | *** | 0.124 | *** | 0.137 | *** |
| PA Index - Active | -1.135 | *** | | | | |
| PA Index - Modertly Active | | | -1.410 | *** | | |
| Daily Physical Activity | | | | | -0.723 | *** |
| Intercept | -1.684 | *** | -1.219 | *** | -1.678 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.11: Coefficient Estimates - Bivariate Probit, Reduced Form Physical Activity Equation, Incidence of Arthritis

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.011 | *** | -0.001 | *** | -0.005 | *** |
| Male | 0.057 | *** | -0.083 | *** | -0.088 | *** |
| Widowed / Separated / Divorced | 0.03 | ** | -0.027 | ** | 0 | |
| Single | 0.105 | *** | -0.026 | ** | 0.076 | *** |
| Martial Status - Not Stated | 0.108 | | -0.119 | | 0.076 | |
| Employed | -0.19 | *** | -0.029 | ** | -0.197 | *** |
| Income ($15,000 - $29,999) | 0.07 | *** | 0.016 | | 0.051 | *** |
| Income ($30,000 - $49,999) | 0.079 | *** | 0.059 | *** | 0.053 | *** |
| Income ($50,000 - $79,999) | 0.12 | *** | 0.098 | *** | 0.077 | *** |
| Income ($80,000 or more) | 0.227 | *** | 0.132 | *** | 0.15 | *** |
| Houshold Income - Not Stated | 0.144 | *** | -0.009 | | 0.093 | *** |
| Welfare main source of income | 0.016 | | -0.027 | | 0.075 | *** |
| Owns Home | 0.106 | *** | 0.05 | *** | 0.06 | *** |
| High School | 0.124 | *** | 0.094 | *** | 0.128 | *** |
| Some College | 0.147 | *** | 0.116 | *** | 0.155 | *** |
| College Graduate | 0.213 | *** | 0.157 | *** | 0.207 | *** |
| Education - Not Stated | 0.175 | *** | -0.164 | ** | 0.092 | |
| Height | 0.615 | *** | 0.155 | ** | 0.473 | *** |
| Kids | -0.154 | *** | -0.045 | *** | -0.127 | *** |
| Canadian Born | 0.031 | ** | 0.041 | *** | 0.025 | ** |
| Strong Sense of Community | 0.212 | *** | 0.068 | *** | 0.222 | *** |
| $\rho$ | 0.882 | *** | 0.920 | *** | 0.836 | ** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.12: Coefficient Estiamtes - Bivariate Probit, Structural Health Equation, Incidence of Asthma

| Participation in Physical Activity: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.006 | *** | -0.005 | *** | -0.007 | *** |
| Male | -0.154 | *** | -0.163 | *** | -0.166 | *** |
| Widowed / Separated / Divorced | 0.008 | | -0.007 | | 0.006 | |
| Single | 0.014 | | 0.001 | | 0.023 | |
| Martial Status - Not Stated | -0.156 | | -0.18 | | -0.146 | |
| Employed | -0.121 | *** | -0.111 | *** | -0.147 | *** |
| Income ($15,000 - $29,999) | -0.013 | | -0.002 | | -0.005 | |
| Income ($30,000 - $49,999) | -0.094 | *** | -0.05 | ** | -0.084 | *** |
| Income ($50,000 - $79,999) | -0.095 | *** | -0.034 | | -0.082 | *** |
| Income ($80,000 or more) | -0.069 | ** | 0.001 | | -0.047 | * |
| Houshold Income - Not Stated | -0.085 | *** | -0.073 | *** | -0.071 | *** |
| Welfare main source of income | 0.221 | *** | 0.173 | *** | 0.227 | *** |
| Owns Home | -0.084 | *** | -0.047 | *** | -0.072 | *** |
| High School | -0.11 | *** | -0.049 | ** | -0.09 | *** |
| Some College | 0.042 | * | 0.086 | *** | 0.064 | *** |
| College Graduate | -0.018 | | 0.054 | *** | 0.012 | |
| Education - Not Stated | 0.058 | | -0.018 | | 0.067 | |
| Height | -0.356 | *** | -0.227 | *** | -0.281 | *** |
| Kids | -0.059 | *** | -0.064 | *** | -0.074 | *** |
| Canadian Born | 0.217 | *** | 0.201 | *** | 0.218 | *** |
| PA Index - Active | -0.031 | | | | | |
| PA Index - Modertly Active | | | -1.098 | *** | | |
| Daily Physical Activity | | | | | -0.399 | *** |
| Intercept | -0.374 | ** | -0.279 | ** | -0.368 | *** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.13: Coefficient Estimates - Bivariate Probit, Reduced Form Physical Activity Equation, Incidence of Asthma

| Physical Activity Index: | Active | | Moderate | | Daily | |
|---|---|---|---|---|---|---|
| Age | -0.011 | *** | -0.001 | *** | -0.005 | *** |
| Male | 0.06 | *** | -0.076 | *** | -0.087 | *** |
| Widowed / Separated / Divorced | 0.032 | *** | -0.026 | ** | 0 | |
| Single | 0.111 | *** | -0.022 | * | 0.076 | *** |
| Martial Status - Not Stated | 0.112 | | -0.109 | | 0.077 | |
| Employed | -0.19 | *** | -0.027 | ** | -0.197 | *** |
| Income ($15,000 - $29,999) | 0.071 | *** | 0.023 | | 0.051 | *** |
| Income ($30,000 - $49,999) | 0.081 | *** | 0.067 | *** | 0.054 | *** |
| Income ($50,000 - $79,999) | 0.123 | *** | 0.105 | *** | 0.077 | *** |
| Income ($80,000 or more) | 0.23 | *** | 0.14 | *** | 0.15 | *** |
| Houshold Income - Not Stated | 0.145 | *** | -0.001 | | 0.092 | *** |
| Welfare main source of income | 0.015 | | -0.029 | | 0.076 | *** |
| Owns Home | 0.106 | *** | 0.05 | *** | 0.06 | *** |
| High School | 0.128 | *** | 0.104 | *** | 0.129 | *** |
| Some College | 0.15 | *** | 0.122 | *** | 0.156 | *** |
| College Graduate | 0.215 | *** | 0.165 | *** | 0.208 | *** |
| Education - Not Stated | 0.165 | ** | -0.155 | ** | 0.093 | |
| Height | 0.628 | *** | 0.165 | *** | 0.475 | *** |
| Kids | -0.149 | *** | -0.041 | *** | -0.127 | *** |
| Canadian Born | 0.034 | ** | 0.045 | *** | 0.025 | ** |
| Strong Sense of Community | 0.227 | *** | 0.073 | *** | 0.224 | *** |
| $\rho$ | 0.882 | | 0.920 | *** | 0.836 | ** |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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