DISCUSSION PAPER SERIES

No. 8499

THE EFFECTS OF CANNABIS USE ON PHYSICAL AND MENTAL HEALTH

Jan C van Ours and Jenny Williams

PUBLIC POLICY

Centre for Economic Policy Research

www.cepr.org

Available online at: **www.cepr.org/pubs/dps/DP8499.asp**

ISSN 0265-8003

THE EFFECTS OF CANNABIS USE ON PHYSICAL AND MENTAL HEALTH

Jan C van Ours, CentER, Tilburg University, University of Melbourne and CEPR
Jenny Williams, University of Melbourne

Discussion Paper No. 8499
August 2011

Centre for Economic Policy Research
77 Bastwick Street, London EC1V 3PZ, UK
Tel: (44 20) 7183 8801, Fax: (44 20) 7183 8820
Email: cepr@cepr.org, Website: www.cepr.org

CEPR Discussion Paper No. 8499

August 2011

ABSTRACT

The Effects of Cannabis Use on Physical and Mental Health *

This paper investigates whether cannabis use affects physical and mental health. To do so, information on prime aged individuals living in Amsterdam in 1994 is used. Dutch data offer a clear advantage in estimating the health impacts of cannabis use because the legal status of cannabis in the Netherlands ensures that estimates are free from confounding with the physical and psychological effects of engaging in a criminal activity. Accounting for selection into cannabis use and shared frailties in mental and physical health, the results suggest that cannabis use reduces the mental wellbeing of men and women and the physical wellbeing of men. Although statistically significant, the magnitude of the effect of using cannabis on mental and physical health is found to be small.

JEL Classification: C41, D12 and I19
Keywords: cannabis use, duration models, mental health and physical health

Jan C van Ours
Department of Economics and CentER
Tilburg University
Room K415
PO Box 90153
5000 Le Tilburg
THE NETHERLANDS

Email:
vanours@uvt.nl

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=121886

Jenny Williams
Department of Economics
University of Melbourne
5th Floor
Economics and Commerce Building
Victoria, 3010
AUSTRALIA

Email:
jenny.williams@unimelb.edu.au

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=137915

* We wish to thank CEDRO, the Center for Drug Research, and the SCO-Kohnstamm Institute of the University of Amsterdam for making their data available, and participants of the CAER Health Workshop and the Second Australasian Workshop on Econometrics and Health Economics for their comments and suggestions. We gratefully acknowledge support from the Australian Research Council, grant number DP0770580.

Submitted 20 July 2011

1 Introduction

Cannabis users account for 80% of the 200 million illicit drug users in the world (UNODC, World Drug Report, 2005). In countries such as the US, the UK and Australia, over 30% of the population have used cannabis.[1] In part, its widespread use reflects the common belief that cannabis is not a particularly harmful drug.[2] The weight of evidence supports this belief, finding that the harms associated with cannabis use are much less serious than those associated with "hard" drugs such as cocaine or heroin and may even be smaller than those associated with alcohol and cigarettes (Nutt et. al, 2010; Nutt et al. 2007; Hall et al. 1999). And while it is generally acknowledged that there are risks associated with long term heavy use of cannabis such as respiratory diseases, cancer and perhaps psychotic disorders, only a small fraction of those who ever use cannabis actually become long term heavy users (Hall and Pacula, 2003; MacLeod et al., 2004; Moore et al. 2007). For the vast majority, there is a dearth of information on the risks associated with their cannabis use. This is an issue because, as shown by Orphanides and Zervos (1995), uncertainty about risk leads to higher demand for drugs and lower welfare than would occur if information on risks were publicly available. It is in this context that we seek to make a contribution by providing new evidence on the impact of cannabis use on health.

In addition to benefiting individuals making decisions about their own cannabis use, knowledge of the health risks of more typical modes of cannabis consumption is a vital input for the development of cannabis policy. In the US state of California, for example, a referendum was recently held asking voters whether cannabis use should be legalized in that state. A casual reading of the debate that surrounded the referendum demonstrates clearly that the accounting of costs and benefits of such a policy change depended crucially on the currently uncertain health impacts of cannabis use (Pacula, 2010). Irrespective of the criminal status of cannabis use, public information about the health risks of drug use can be an effective tool for demand reduction (Pudney, 2010).

Despite the potential welfare benefits of reliable information on the health risks facing the typical cannabis user, there are very few contributions from the economics literature on this issue. Previous studies from economics that do attempt to tease out causal effects suggest that there may be risks to both mental and physical health from cannabis use. For

[1]Its legal status was established almost globally under the 1961 Single Convention on Drugs (UN 1961) when cannabis use was uncommon in most western countries.

[2]This view was espoused in the prestigious journal, Lancet's editorial in 1995, where it was stated "The smoking of cannabis, even long term, is not harmful to health." (p. 1241 Editorial).

example Williams and Skeels (2006) find the probability of being in very good or excellent health to be 8% lower amongst those who consumed cannabis in the past year compared to those who had not and 18% lower for those who reported weekly use. Van Ours and Williams (2011) find that cannabis use increases the likelihood of mental health problems, with the probability of experiencing mental health distress increasing with the frequency of past year use. While each of these studies considers a single dimension of wellbeing, there is significant evidence that poor mental health is correlated with poor physical health (Aneshensel, Frerichs and Huba, 1984).[3] This suggests that that the impact of cannabis use on health should be studied in a framework that accounts for the potential for shared frailties in the domains of physical and psychological wellbeing.

This paper is the first to address the potential for common frailties linking physical and mental wellbeing in studying the health effects of cannabis use. We do so using the discrete factor approach (Mroz, 1999) in which unobserved heterogeneity from a discrete distribution is permitted to be correlated across the equations for the two domains of health. In addition to unobserved factors linking physical and mental health, a key challenge in studying the health effects of cannabis use is the potential for common unobserved factors affecting health and selection into cannabis use. This is an issue because the presence of endogenous selection renders standard estimation techniques unreliable. We also use the discrete factor approach to address this issue. To so so, we introduce unobserved heterogeneity from a discrete distribution into the dynamics of cannabis use. By permitting the heterogeneity terms in the cannabis use dynamics and health equations to be correlated, we account for the potential for endogenous selection in estimating the impact of cannabis use on health.

A second contribution of this study is that it provides estimates of the physical and psychological effects effects of using cannabis that are free from confounding with the effects of engaging in a criminal activity. This is an issue for the previous studies as their empirical analyses are based on data from Australia, where cannabis use is a criminal offense in half of the States and Territories. As the criminal status of cannabis is not accounted for in these studies, the health effects they measure capture both the direct effects of using cannabis and the indirect effects attributable to dealing in illegal markets and breaking the law. In contrast, the empirical analysis in this paper is based on individuals living in Amsterdam. Dutch data offer a clear advantage in estimating the health impacts

[3]This may be attributed to common unobserved confounders such as stress or a lack of social support, or it may reflect a causal link.

of cannabis use because, as explained below, cannabis can be purchased and consumed legally in the Netherlands. As a consequence, our estimates are free from confounding with the physical and psychological effects of engaging in a criminal activity.

A final contribution of this research is that it extends earlier studies by exploring a richer set of dimensions of cannabis use than previously considered. Earlier studies have considered the effect of being a current user and past user as well as the intensity of use in the last year. In this paper, in addition to considering the effect of being a current or past user, we explore the duration of use amongst current users and duration of use amongst past users in assessing the health effects of cannabis use. This allows us to determine whether the health effects of cannabis use accumulate with duration of use as one would expect from standard economic theories of health.

Our results suggest negative and significant health impacts of cannabis use for men and women. Although we are unable to detect differential health effects of cannabis use based on the duration of use for current or past users, for both women and men we find that cannabis use decreases psychological wellbeing. For men, using cannabis also has an adverse impact physical health. In order to give some perspective on the size of the estimated effects, we compare them to the effect size of having migraine headaches and chronic health conditions reported in the epidemiology literature. Doing so reveals that while statistically significant, the estimated effect of using cannabis on mental and physical wellbeing is small.

The rest of the paper is laid out as follows. Section 2 provides information on the legal system governing cannabis use in the Netherlands and describes the data used in our analysis. Section 3 contains the empirical analysis, section 4 an extensive sensitivity analysis, and section 5 discusses our findings.

2 Cannabis use in Amsterdam

2.1 Data

The Netherlands has a special type of drug policy. The main aim is to protect the health of drug users, the people around them and society as a whole.[4] Regulations on drugs are laid down in the Opium Act, which draws a distinction between hard drugs, such as cocaine and heroin, and soft drugs such as cannabis. The possession of hard drugs is a

[4] An international perspective on Dutch drug policy is given in Boekhout van Solinge (1999).

crime. However, a policy of tolerance is applied to soft drugs. Under this policy, while the possession of small quantities of cannabis for personal use is a misdemeanor (and potentially punishable by a fine) official guidelines prescribe that these offenses are not prosecuted. The policy of tolerance has been in place since 1976. It has also been applied to the sale of cannabis by house dealers since 1979, and subsequently "coffee shops", meeting strict criteria: no overt advertising, no hard drugs, no nuisance, no underage clientele, and no large quantities (Korf, 2002). Consequently, both the use and procurement of cannabis can be can be achieved without turning to illicit markets and without fear of prosecution. This is a distinctive feature of the Dutch system and one that enables us to estimate the health consequences of cannabis use free from the confounding effects attributable to engaging in illegal behavior.

We use data from Amsterdam, which has a population of 700,000 inhabitants and around 300 recognized, so-called "coffee-shops" where cannabis can be purchased. The individual level survey data were collected in 1994 and are representative of inhabitants of Amsterdam aged 12 years and older.[5] The Municipal Population Registry of Amsterdam was used as the sampling frame and the survey was conducted between April and August 1994. Although the response rate was just over 50%, the sample appear to be a good representation of the population (Sandwijk et al., 1995).[6] Moreover, individuals who originally declined the survey or were repeatedly not at home were re-approached to investigate the source of the low response rate and whether non-responders were very different from those who did participate in the survey. This revealed that: (1) there was no substantial differences between those who did respond to the original survey and those who did not, (2) indifference was the main reason for non-response, and (3) the prevalence of cannabis use was lower amongst non-responders than amongst those who did respond to the initial survey. The overall prevalence rate for cannabis use was not, however, significantly affected by differences between response and non-response groups (Sandwijk et al., 1995).

Our analysis is based on information on 818 men and 870 women. We focus on prime age individuals, i.e. individuals aged 26 to 50 years. The data on cannabis use are based on self-reported information, which is the norm for analyses of drug consumption. Because immigrant groups tend to underreport cannabis use the analysis is restricted to native

[5] Information on cannabis use has been collected in other years as well, but the 1994 survey was unique in the collection of health information; see Abraham et al. (2003) for a detailed description.

[6] The only substantial difference is that people originating from Turkey, Morocco, Surinam and the Antilles are under-represented. Our analysis is confined to native Dutch inhabitants of Amsterdam.

Dutch inhabitants of Amsterdam. Definitions of variables used in the analysis can be found in the Appendix.

Our measures of health come from the SF-36. We use the Physical Functioning scale to represent physical health and the Mental Health scale to represent mental health. The Physical Functioning scale is based on 10 items from the SF-36 and the Mental Health scale is based on 5 items. Both scales are constructed using the scoring rules for the RAND 36 Item Health Survey 1.0. The scores are then normalized to have a sample mean of 50 and standard deviation of 10. Note that larger numbers represent better health status. For brevity, we refer to the normalized Physical Functioning scale and the normalized Mental Health scale as the index of physical health and the index of mental health hereafter.

Table 1 presents characteristics of the data used for our analysis. As shown in panel *a* of Table 1 the average age of individuals in our sample is 36.4 years for males and 36.7 years for females. The distribution of decade of birth is similar across gender with 37% of males and 38% of females born in the 1950's and 45% of males and 43% if females born in the 1960's (the omitted category is born in the 1940's). Compared to males, females in the sample are more likely to be single (43% for females compared to 39% for males) and more likely to have children (41% for females compared to 31% for males). Females also have a higher level of education than males with 47% having a tertiary education and 23% having a secondary education compared to 43% and 28% respectively for males (the omitted category is primary education). In terms of cannabis use, 49% of males and 41% of females report having ever use cannabis (past plus current users), with 21% of males and 9% of females reporting having used in the past year (current users), and 14% of males and 6% of females having used in the past month. The average age at first use is similar across gender, at 19.5 years for males and 19.7 years for females. Males tend to have longer histories of use, with an average duration amongst past and current user of 11 years compared to 8.3 years for females. In our sample, 4% of males and 5% of females have parents who had used cannabis. Finally Table 1 *a* shows lifetime use of tobacco and cocaine for sample members. The majority of males and females have smoked cigarettes (75%) while 15% of men and 10% of women have used cocaine.

2.2 Stylized facts

In the following analysis we differentiate between cannabis users who have used in the twelve months prior to survey, whom we refer to as current users, and those who have used at some point in the past but stopped using more than 12 months prior to survey, whom we refer to as past users. Current users can also be described as those who have started to use cannabis and have not yet quit, while past users are those who have both started and quit use. Characterizing cannabis use status in terms of the dynamics of cannabis use lends itself to analysis in terms of the rate at which people start and stop cannabis use. In modeling these rates, the outcomes of interest are the age at which the respondent first used cannabis and, amongst those who have used cannabis, the age at which they quit use.

Figures 1*a* and *b* show the starting rates of cannabis use and quitting rates, respectively, for men and women in the sample. Figure 1*a* shows the starting rates, which are transition rates from non-use to use for each particular year of age, conditional on not having used up until that age. In calculating age-specific starting rates, those who have not started to use cannabis at the time of survey are considered to have a duration until use that is right censored. As can be seen in Figure 1*a*, the hazard of starting cannabis use peaks at 18 years old for men and women. The starting rate increases from age 12, reaching a maximum at age 18 and drops off dramatically after the age of 20.

Figure 1*b* shows the quit rates, defined as the probability of ceasing to use cannabis at a particular duration of use, given that the individual has not stopped up until that duration. If an individual is still using cannabis at the time of survey, the duration of use is considered to be right censored. As shown in Figure 1*b*, the quit rate for cannabis use is very high in the first year of use after which it remains fairly constant.

Figure 2 graphs the distribution of the physical and mental health indices for males and females in our sample. Indeed, most women and the majority of men are in good physical health while only few women and men have bad physical health according to these measures. The mental health index is more evenly distributed but again there are more people in good mental health than in bad mental health. While the distribution of the index of mental health displays greater variation than the physical health index, the two are positively correlated, with a correlation coefficient of 0.3.

Panel *b* of Table 1 shows the average values of the index of physical and mental health for males and females by their cannabis use status. Cannabis use status is categorized as current user (used in the last year), past user (used in lifetime but not in the past year), and never used. Table 1b shows that for both males and females, there is very little difference in the average physical health score for those who have never used cannabis and those who have used (either in the past or currently). In fact, the average physical health scores are not significantly different across user type. In contrast, the average mental health scores of men and women are highest for never users and lowest for current users, and the difference across user types are generally significant.[7] The evidence in Table 1b suggests that cannabis use may impact on the mental health but not physical health of both men and women. However, this descriptive analysis fails to account for the correlation in the distributions of physical and mental health indices, and it does not account for the potential correlation of unobserved characteristics determining health and cannabis use outcomes. We address these issues in the following section.

3 Empirical analysis

Our goal is to estimate the impact of cannabis use on physical and mental health accounting for shared frailties across the two domains of health. The main challenge in doing so is that the decision to use cannabis and health status may be affected by circumstances faced in childhood and early adulthood as well as personal characteristics that are not observed. In order to be able to assess whether there is a causal link between cannabis use and health, common unobserved 'confounding' factors that may be a source of spurious association must be taken into account. We do this by using the discrete factor approach.

The discrete-factor approach was proposed by Heckman and Singer (1984) and further developed by Mroz (1999) for application to regression models with endogenous dummy variables. Mroz demonstrates that when the idiosyncratic error terms for the latent endogenous variable and the outcome of interest have a bivariate normal disturbance, the discrete-factor method compares favorably to the usual maximum likelihood estimator (MLE) in terms of precision and bias. Furthermore, the discrete factor approximation outperforms both the MLE and the Two Stage estimator (TSE) when the disturbances are non-normal.[8]

Our model is a four equation system consisting of an equation for physical health, mental health, the hazard rate for starting cannabis use, and the hazard rate for quitting cannabis use. In order to account for endogenous selection into cannabis use and shared

[7]For males, the differences between never use and past user as well as never user and current user are significantly different, while for females the average mental health score of current users is significantly different from past and never users.

[8]The discrete factor model also outperforms MLE and TSE in the presence of weak instruments in models with non-normal errors. This is of particular salience given that state level policy variables are often relied upon to identify the effects of substance use and these policy variables tend to be only weakly predictive of substance use.

frailties in health, each equation includes an unobserved heterogeneity term that is drawn from a joint discrete distribution. The unobserved heterogeneity terms are assumed to be uncorrelated with observed characteristics other than those measuring cannabis use. Identification of the four equation system with correlated errors comes from functional form and distributional assumptions. In the case of cannabis uptake and quitting, we follow Heckman and Singer (1984) and assume mixed proportional hazard functions. Similar to Mroz (1999), identification of unobserved heterogeneity in the health equations relies on their linear functional form and the assumption that their idiosyncratic errors are normally distributed.

As with any attempt to discern causal effects of endogenous variables, identification of the parameters of interest is ultimately based on untestable assumptions. We have, however, attempted to explore issues related to identification and model specification in an extensive sensitivity analysis that is reported in Section 3.4. The main advantage of our approach is that it is possible to account for endogenous selection into cannabis use without having to rely on instrumental variables which are difficult, if not impossible, to find. However, as physical and mental health are only measured at one moment in time, we are not able to address the potential for reverse causality, whereby poor health leads to cannabis use. To account for this, we would at the very least need to have time varying information on the relevant health variables.

We build up our empirical model in three steps. First, we model the dynamics of cannabis use (section 3.1). Next we model physical and mental health, ignoring selection into cannabis use (section 3.2). We then bring cannabis use dynamics together with the health equations in order to account for selectivity in section 3.3. Section 3.4 contains an extensive sensitivity analysis to investigate the robustness of our findings.

3.1 Cannabis use

Most people use cannabis without becoming addicted. If they thought they would become addicted, they would not ever use cannabis. In practice, however, information about ones addictive "type" is not known before the decision to use is made. Orphanides and Zervos (1995) show that if there is uncertainty with regard to ones own addictive nature, then the decision to use a drug is based on balancing the instant pleasure derived from using an addictive substance against the probabilistic disutility incurred if one becomes addicted. If an individual is not the addictive type, they may use cannabis at low levels infrequently without becoming addicted and hence without incurring the disutility of the harms associated with addiction. If the individual is the addictive type and they learn this before becoming addicted, they will quit use. Otherwise, if they learn too late that they have an addictive personality with respect to cannabis, they will continue to use and do so at a higher level (Orphanides and Zervos, 1995). With this in mind, we study the dynamics of cannabis use accounting for unobserved characteristics that may be correlated across the uptake and quitting decisions.

Specifically, the determinants of the starting rates and quit rates for cannabis use are investigated using the mixed proportional hazard model with flexible baseline hazards (see for an example: Van Ours, 2006). Differences between individuals in the rate at which they start using cannabis are characterized by observed characteristics, elapsed duration of time they are exposed to potential use and unobserved characteristics. Age 12 is assumed to be the time at which individuals are first exposed to cannabis. The starting rate for cannabis at age t conditional on observed characteristics x and unobserved characteristics u^s is specified as (omitting a subscript for individual):

$$\theta^s(t \mid x, u^s) = \lambda^s(t) \exp(x'\beta + u^s) \tag{1}$$

where $\lambda^s(t)$ represents individual age dependence, and the superscript s refers to starting. We model flexible age dependence by using a step function:

$$\lambda^s(t) = \exp(\Sigma_k \lambda_k^s I_k(t)) \tag{2}$$

where k (= 1,..,N) is a subscript for age-intervals and $I_k(t)$ are time-varying dummy variables for subsequent age-intervals. Age intervals are specified to be one year up until age 30, and the last interval refers to ages over 30. Because a constant term is also estimated, λ_1^s is normalized to 0.[9]

The conditional density functions for the completed durations of non-use can be written as

$$f^s(t \mid x, u^s) = \theta^s(t \mid x, u^s) \exp(-\int_0^t \theta^s(s \mid x, u^s) ds) \tag{3}$$

The quit rates are also assumed to have a mixed proportional hazard specification. The

[9] The cannabis uptake and quitting equations can be considered semi-reduced forms as neither physical nor mental health enter these equations.

quit rate for cannabis at duration of use τ conditional on observed characteristics z and unobserved characteristics u^q is specified similarly as:

$$\theta^q(\tau \mid z, u^q) = \lambda^q(\tau) \exp(z'\gamma + u^q) \tag{4}$$

where z contains the age at which the individual started using cannabis in addition to the variables contained in x, $\lambda^q(\tau)$ represents individual duration dependence and the superscript q refers to quit.[10] Duration dependence is again modeled as piecewise constant:

$$\lambda^q(\tau) = \exp(\Sigma_m \lambda^q_m I_m(\tau)) \tag{5}$$

where m (= 1,..,M) is a subscript for duration of use-intervals and $I_m(\tau)$ are time-varying dummy variables that are one in subsequent duration intervals. The conditional density functions for the completed durations of drug use can be written as

$$f^q(\tau \mid z, u^q) = \theta^q(\tau \mid z, u^q) \exp(-\int_0^\tau \theta^q(s \mid z, u^q) ds) \tag{6}$$

Individuals who have not used cannabis at the time of the survey are assumed to have a right-censored duration of non-use. Similarly, individuals who have started cannabis use and are still using at the time of the survey have a right-censored duration of use.

In order to allow for correlation across uptake and quitting decisions we specify the joint density function of the duration of non-use and the duration of use conditional on z and x as

$$f^{sq}(t, \tau \mid x, z) = \int_{u^q} \int_{u^s} f^s(t \mid x, u^s) f^q(\tau \mid z, u^q) dG(u^s, u^q) \tag{7}$$

where $G(u^s, u^q)$ is assumed to be a discrete distribution with s points of support. In practice, we are able to identify three points of support in the joint distribution, (u^s_1, u^q_1), (u^s_2, u^q_2), (u^s_3), with $u^q_2 = u^s_3 = -\infty$ to allow for the possibility of zero starting rates and zero quit rates. The specification of the distribution of unobserved heterogeneity implies that conditional on the observed personal characteristics (including age and duration of use) there are three types of individuals. The first type represents the "experimenters" who have a positive starting rate and a positive quit rate. The second type represents the

[10]Note that quits are assumed to be permanent. Once individuals have decided to quit use they don't return to use again in this model.

“persistent users” who have a positive starting rate and a zero quit rate. Individuals in this group start using and do not stop. The third type are “abstainers”. They have a zero starting rate, and therefore the quit rate is non-existent.

The associated probabilities are denoted as

$$\Pr(u^s = u_1^s, u^q = u_1^q) = p_1 \qquad \Pr(u^s = u_2^s, u^q = u_2^q) = p_2 \qquad \Pr(u^s = u_3^s) = p_3$$

and are assumed to have a multinomial logit specifications $p_n = \frac{\exp(\alpha_n)}{\Sigma_n \exp(\alpha_n)}$, with $n = 1, 2, 3$ and α_3 normalized to zero.

To understand the dynamics of cannabis use, information about the past is required. Specifically, information is needed on characteristics and circumstances faced from the time the individual was potentially first confronted with the choice to start to use cannabis, and conditional on using cannabis, from the time the individual was first confronted with the decision to quit. Ideally, the information is time-varying over the relevant period of life, reflecting the changing circumstances shaping individuals choices. Information that could be important includes family situation, experiences at school, changing cannabis supply conditions, and the price of cannabis as well as the price of substitutes and complements. Unfortunately, this type of information is rarely available, and this is the case in the current analysis.[11]

The observable characteristics that we control for are indicators for educational attainment (secondary education and tertiary education with primary education as the omitted category), and cohort indicators (born in the 1950's, born in the 1960's with born in the 1940's as the omitted category). These individual characteristics are assumed to be known at the time an individual first faces the decision of whether to start using cannabis. Although the highest level of education may be attained long after the use of cannabis started one might assume that this level represents ability rather than educational investment. In the interpretation of the parameter estimates of the starting rates and quit rates it is assumed that educational level represents ability, and this is taken to be exogenous with respect to drug use and ignores the possibility that cannabis use has an effect on the educational level attained (See Van Ours and Williams, 2009).

The parameters of the models are estimated using the method of maximum likelihood

[11] Variables that indicate personal characteristics at the time of the survey, such as marital status and presence of children, are not very useful because, in addition to being potentially endogenous, the do not reflect circumstances at the time individuals first face the decision of whether or not to use cannabis. Or, conditional on using cannabis whether or not to stop using.

and are reported in Table 2.[12] The general picture that emerges from the parameter estimates in Table 2 is that males and females from more recent birth cohorts with a greater level of education have a higher starting rate for cannabis use compared to those from earlier cohorts and with lower levels of education. For men, those with a secondary level of education and born in the 1950's have a lower quit rate compared to men with a lower level of education and those born more recently. For women, quit rates are higher for those born in the 1960's (compared to earlier cohorts) and those who started using cannabis at older ages. The later effect is also found for Australian men and women (see Van Ours and Williams, 2007).

The results in Table 2 also show that unobserved heterogeneity is important and that three types of individuals can be distinguished. Conditional on observed characteristics, the estimates imply that 47.6% of males and 50% of females are of the type who have a positive starting rate and a positive quit rate (type 1 - the experimenters); 7.1% of males and 2.4% of females are of the type who have a positive starting rate and a zero quit rate (type 2 - persistent users); and 45.3% of males and 47.6% of females are of the type who have a zero starting rate (type 3 - never users).[13]

3.2 Health

The starting point for the analysis of the determinants of physical health and mental health are linear equations in which the error term contains two components, ϑ_j and ϵ_j where j is an indicator that has two values, $j = p$ if the equation relates to physical health and $j = m$ if it relates to mental health. Each of the error components are assumed to be uncorrelated with the variables contained in x^h. The first component, ϑ_j, is assumed to be drawn from a discrete distribution with an unknown number of points of support and is potentially correlated with the unobserved heterogeneity impacting on the dynamics of cannabis use. The second component of the error term, ϵ_j is assumed to be drawn from a normal distribution and uncorrelated with cannabis use. For the moment we ignore the potential for selection into cannabis use (ϑ_j is uncorrelated with (u^s, u^q)). Omitting the subscript for individual we assume the following relationship:

$$h_j = x_h'\beta_j + c'\delta_j + \vartheta_j + \epsilon_j \qquad \text{for} \quad j = p, m \tag{8}$$

[12] The parameters on the age dependence terms in the starting rate and the duration dependence variables in the quit rates are not reported in the table but are available on request.

[13] We tried to identify additional masspoints in the discrete distribution of unobserved heterogeneity but didn't succeed.

where h represents the health status of the individual, x_h represents the personal characteristics which may affect health (age, education, marital status, presence of children in the household), c represents cannabis use characteristics (indicators for being current or past cannabis user, duration of current cannabis use, duration of past cannabis use). Finally, β_j and δ_j are a vector of parameters.

In practice we find that the ϑ_j's, $j = p, m$, each have two points of support $(\vartheta_{j,1}, \vartheta_{j,2})$. Thus, allowing for correlation across these unobserved heterogeneity terms for physical and mental health, the joint distribution has up to four points of support with

$$\begin{aligned} &\Pr(\vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,1}) = p_1 \quad \Pr(\vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,2}) = p_2 \\ &\Pr(\vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,1}) = p_3 \quad \Pr(\vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,2}) = p_4 \end{aligned}$$

where p is assumed to have a multinomial logit specification. This implies that, conditional on the observed characteristics and cannabis use, there are four types of individuals who differ both in physical and mental health frailties.[14]

This bivariate system is estimated using maximum likelihood and the results are reported in panel a of Table 3. We can clearly distinguish four groups with differing unobserved physical and mental health characteristics. More than three-quarters of the men and women are of the type with good physical and mental health, around 1% males and 4% of females are of the type with good mental health and poor physical health, 20% of men and 14% of women are of the type poor mental health and good physical, while 4% of males and 5% of females have poor physical and mental health.

Treating the cannabis use variables as exogenous, we find that neither current use, duration of current use, past use, nor duration of past use are significantly related to physical health for men or women. We do find some evidence that cannabis use impacts on mental health. For both men and women, past cannabis use is associated with a significantly lower level of mental wellbeing. There is also some evidence that amongst men who have used in the past year, mental health is decreasing in the duration of use.

These somewhat weak findings with respect to our rich set of cannabis use measures may reflect insufficient variation in the data (conditional on age) to be able to distinguish duration effects separately from use effects. We investigate this issue in panel b of Table 3, which reports a specification in which the coefficients on the duration of current use and the duration of past use are constrained to be zero. The last row of the panel reports the LR test statistic for the joint hypothesis that duration effects are zero in the mental

[14]So, across these types physical health and mental health are correlated, but not perfectly.

and physical health equations. As can be seen from Table 3, we are unable to reject this hypothesis at conventional levels of significance. The estimates from the constrained model indicate that current but not past cannabis use diminishes the physical health of males and that both past and current cannabis use decreases the mental wellbeing of males and females. The magnitude of the point estimates suggest that for females, the effect of past use is smaller than the effect of current use, while for males, the opposite is found. However, these effects are not precisely estimated and although (for both men and women) the estimated coefficients on current and past cannabis use in the mental health equation are significantly different from zero, they are not statistically different from each other. Similarly, the physical health effects of past and current use are not significantly different from each other for males (or females). Indeed, a shown in panel *c* of Table 3, on the basis of an LR test, we are unable to reject the null hypothesis of equal effects for past and current use on the mental and physical health indices for both men and women. For this specification we find that cannabis use reduces the mental wellbeing of males and females by 0.254 and 0.194 standard deviations respectively. We also find that cannabis use reduces the physical health index of males by 0.075 of a standard deviation. We find no significant impact of cannabis use on the physical health of women in our sample.

Estimates for the full set of control variables are reported for the specification given in panel *a*. As these estimates are not sensitive to the measures of cannabis use included in the model, we do not repeat them for specifications found in panels *b* and *c*. The reported estimates in panel *a* show that the age-health profile is quite flat for our sample of 26-50 year olds. For example, aging a male by one year reduces his index of physical health by 0.01 of a standard deviation and his index of mental health by 0.013 of a standard deviation. For females, these effects are estimated to be 0.014 and 0.009 respectively. We find that higher levels of education are associated with better physical health for males and females but worse mental health for males. Being single does not appear to affect the physical health of men or women, but it reduces their mental health by 0.22 and 0.27 of a standard deviation respectively. Having children, on the other hand, improves the mental health of men and women by 0.14 and 0.12 of a standard deviation respectively. In addition, having children improves the physical health of women by 0.16 of a standard deviation but has no significant effect for men.

3.3 Cannabis use and health

As discussed above, we cannot rule out the possibility that individuals select into cannabis use on the basis of unobserved characteristics that also influence their health outcomes. To investigate this possibility in more detail we estimate a model that allows for the possibility that the unobserved heterogeneity terms in the health equations are correlated with the unobserved heterogeneity in the cannabis use dynamics. Combining the three "types" in the unobserved heterogeneity for cannabis use dynamics with the four "types" in the joint distribution of unobserved heterogeneity for physical and mental health implies a joint discrete distribution of unobserved heterogeneity with 12 points of support:

$$
\begin{aligned}
&\Pr(u^s = u^s_1, u^q = u^q_1, \vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,1}) = p_1 \quad &&\Pr(u^s = u^s_2, u^q = u^q_2, \vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,1}) = p_2 \\
&\Pr(u^s = u^s_3, u^q = u^q_3, \vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,1}) = p_3 \quad &&\Pr(u^s = u^s_1, u^q = u^q_1, \vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,2}) = p_4 \\
&\Pr(u^s = u^s_2, u^q = u^q_2, \vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,2}) = p_5 \quad &&\Pr(u^s = u^s_3, u^q = u^q_3, \vartheta_m = \vartheta_{m,1}, \vartheta_p = \vartheta_{p,2}) = p_6 \\
&\Pr(u^s = u^s_1, u^q = u^q_1, \vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,1}) = p_7 \quad &&\Pr(u^s = u^s_2, u^q = u^q_2, \vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,1}) = p_8 \\
&\Pr(u^s = u^s_3, u^q = u^q_3, \vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,1}) = p_9 \quad &&\Pr(u^s = u^s_1, u^q = u^q_1, \vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,2}) = p_{10} \\
&\Pr(u^s = u^s_2, u^q = u^q_2, \vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,2}) = p_{11} \quad &&\Pr(u^s = u^s_3, u^q = u^q_3, \vartheta_m = \vartheta_{m,2}, \vartheta_p = \vartheta_{p,2}) = p_{12}
\end{aligned}
$$

The p_n $(n = 1, .., 12)$ are assumed to have a multinomial logit specification.

The four equation system, consisting of the equation for the duration until uptake of cannabis, the duration until quitting cannabis, the equation for mental health and the equation for physical health, is estimated jointly using maximum likelihood. Table 4 reports the resulting parameter estimates. Since many of the parameter estimates are very similar to those presented in Tables 2 and 3 we limit the presentation to the cannabis use variables. The structure of Table 4 is similar to Table 3. In panel *a* we present the health effects of cannabis use distinguishing between past and current use and allowing the effects of duration of use to differ between current and past users. In panel *b* we restrict the effects of duration of use to be zero, while in panel *c* the effects of past and current use are restricted to be equal. As with the findings from Table 3, for the specification reported in Table 4 we cannot reject the hypothesis that the duration of cannabis use variables have no significant effect on the health indicators. Nor can we reject the hypothesis that past cannabis and current cannabis use have an equal effect on physical health and on mental health.

Estimates of the coefficients for the multinomial logit model of the distribution of unobserved heterogeneity and the corresponding probabilities for model *c* are also reported in Table 4. As shown, the joint distribution of unobserved heterogeneity has 11 points of support for men and 12 points of support for women. The lower part of the table provides details on both distributions, from which it is clear that the marginal distributions correspond to those in Tables 2 and 3.

The last row of panel c of Table 4 contains the LR test statistic for the null hypothesis that cannabis dynamics and health are independent. For men, independence of cannabis use and health is rejected for at the 5% level of significance. After taking the correlation of unobserved heterogeneity into account, the effect of cannabis use on physical health for males increases in magnitude (and significance). This suggests that the unobserved heterogeneities are positively correlated so that, conditional on observed characteristics those who are more likely to use cannabis are also more likely to be in good physical health. In terms of the magnitude of the effect, on average a male cannabis users' physical health status is estimated to be 0.09 of a standard deviation below the average health index of a male who has never used cannabis.

Accounting for correlation in unobserved heterogeneity reduces the estimated effect of cannabis use on mental health for men, but the point estimate remains significantly different from zero. This suggests a negative correlation in unobservables, consistent with those with worse mental health selecting into cannabis use. We estimate that on average, male cannabis users have a mental health index that is 0.14 standard deviations lower than the mental health of an otherwise similar male who has never used cannabis.

For women we are unable to reject the null hypothesis of independent unobserved heterogeneity components in the cannabis dynamics and health. Indeed, the parameter estimates of the effects of cannabis use on physical and mental health are not much affected when we allow for correlated error terms. We estimate that female cannabis users have a mental health index that is 0.15 standard deviations lower than the mental health index of a female who has never used cannabis.

In order to have some perspective on the magnitude of the estimated effects of cannabis use, we conduct a within-sample comparison with the effect of personal characteristics on the health indicators. We find that the effect of cannabis use on mental health is somewhat smaller than the magnitude of the effect of being single (as compared to be part of a multi-person household) but it is larger than the effect of not having children.

We can also get a sense of perspective about the health impacts of cannabis use we find by comparing them to the effect sizes of alternative determinants of health reported in epidemiological studies based on the SF-36. The effect size of a characteristic is calculated by taking the difference in means across samples with and without the characteristic and diving this difference by the pooled standard deviation. For example, using the same Amsterdam data as used in this study, Aaronson et al. (1998) find an effect size of going from none to one chronic condition of 0.36 for the Physical Functioning scale and 0.38 for the Mental Health scale.[15] Aaronson et al. (1998) also report effect sizes for a sample of individuals prone to migraines. The effect size of having had a migraine in the two weeks preceding survey was calculated to be 0.13 for the Physical Functioning scale and 0.25 for the Mental Health scale. On this basis, the impact of cannabis use on physical health is smaller than than the effect of having suffered a migraine in the past 2 weeks and it is around one quarter of the effect of having a chronic condition. In terms of mental health, the effect of using cannabis is smaller than having suffered a migraine and is around one half of the effect of having a single chronic condition. As effect sizes of around 0.2 are considered to be small, we can conclude that cannabis use has a small effect on the mental health of men and women and on the physical health of men.

3.4 Sensitivity analysis

To investigate the robustness of our findings we performed a wide range of sensitivity analyses. These include accounting for the frequency of drug use amongst current users, and probing the sensitivity of our findings to various forms of misspecification, such as omitting time varying cofactors and including potentially endogenous cofactors, and accounting for differential effects across demographic groups. We also attempt to investigate the sensitivity of our findings with respect to identifying assumptions. The results of this analysis are reported in Table 5. For the ease of comparison, the key results from our baseline model are reported in panel *a* of Table 5.

Our first robustness check investigates whether we are able to discern with our data a significant difference between past and current cannabis use effects if we employ a higher frequency of use measure. We do so by adding an indicator for monthly use to our baseline model. The results from doing so are reported in panel *b* of Table 5. The coefficient on this variable measures the additional effect of monthly use compared to any use in the past year. The effect of use in the past month is found by summing the coefficients on past year and past month use. Although the point estimates on the monthly use variable are generally negative as expected, they are not significant except in the equation for physical health for males. It is not therefore surprising that, on the basis of an LR test (statistic

[15] The analysis included individuals aged 16-97 and pooled males and females.

reported in the last row of Panel *c* of Table 5) we are unable to reject the hypothesis that the coefficients on monthly use are jointly insignificant in the models of health for men and women. We conclude that accounting for more frequent recent use of cannabis does not alter our findings.

A potential source of misspecification in our model is that it does not account for the use of other drugs, both licit and illicit. This is an issue because, in addition to potentially impacting on health, the use of other substances tends to be positively correlated with the use of cannabis. For example in the sample analyzed here, of the 21 men and 86 women who have ever used cocaine, only 4 men and 4 women have not used cannabis. Among the cannabis users in the sample, 71% of males and 76% of females have not also used cocaine. It therefore could be the case that the health effects that we are attributing to cannabis use are in fact being driven by cocaine users. In order to investigate this, we add an indicator for having ever used cocaine in our baseline specification. The results are reported in panel *c* of Table 5. Although the point estimates on the cocaine use indicator variable are generally negative, they are never significant. As shown by the LR test statistic reported in the final row of panel *c*, we are unable to reject the null hypothesis that cocaine use has no additional effect on mental or physical health for this sample.

We also explore whether the effects we find for cannabis are being driven by cigarette use. There is a strong correlation between cannabis and cigarette use in our sample, with 60% of males and 51% of females who have ever smoked cigarettes also reporting cannabis use. Amongst those reporting to have ever used cannabis, only 15% of males and 7% of females report no cigarette use. The results from including an indicator for lifetime use of cigarettes in the baseline model are reported in Panel *d* of Table 5. They show that for men, cigarette use has no significant effect on physical health or mental health. Moreover, the LR test statistic shows that we cannot reject the hypothesis that using cigarettes has no significant effect on the health indicators of men. For women however, we do reject the hypothesis that the effects of cigarette use are jointly zero. Specifically, we find that that cigarette use is associated with significantly lower mental health for women.[16] While cannabis is also found to have a negative effect on mental health, it is measured imprecisely and we are unable to reject either the hypothesis that is has the same effect as cocaine or that it has no significant effect. These estimates are based on a model that accounts for

[16]A possible reason for the parameter of tobacco use to be significantly different from zero is reversed causality. Unfortunately our data do not allow us to investigate this possibility. For this we would need better data in particular on the evolution of the health status over time would be helpful in identifying potential reversed causality.

selection into the use of cannabis but not for potential selection into the use of tobacco.

We further explore this issue in panel e of Table 5. In this specification, we ignore the selectivity into cannabis use and we account for potential selection into cigarette use. We find that after accounting for selectivity, cigarette use has no significant effect on either physical or mental health of males and females. As shown in panel e of Table 5, we also find that cannabis use is associated with significantly lower mental health for males. In panel f we modify the model reported in panel e by constraining the direct physical and mental health effects of cigarette use to be zero but allow for indirect effects through the correlated error structure. As shown in the last row of panel f, we are unable to reject the hypothesis that cigarette use has no significant direct effect on the health indicators on the basis of an LR test.[17]

A further potential source of misspecification in our baseline model is that we do not account for time varying cofactors. This may be an issue as, in 1976 the Netherlands formally introduced the policy of tolerance towards cannabis and this change in policy regime is likely to have significantly altered the nature of the cannabis market. To examine whether our findings are sensitive to these changes, and common time varying influences more generally, we introduce calendar time fixed effects into the hazard for cannabis uptake.[18] Panel g of Table 5 reports the resulting parameter estimates. As shown by the LR test in the last row of the panel, the calendar time effects are jointly significant in the models for both males and females. Nonetheless, the estimates of the parameter on cannabis are hardly affected. Clearly whatever the effects of calendar time are, they do not influence the estimates of the effects of cannabis use on the health indicators.

As discussed in Section 3.1 we interpret educational attainment as a measure of ability, assuming this to be exogenous with respect to drug use and ignoring the possibility that cannabis use has an effect on the educational level obtained. Panel h of Table 5 shows the relevant parameter estimates if we exclude the educational variables from the cannabis starting rate and cannabis quit rates. As shown by the LR test statistics, omitting the educational variables has significant effects on the overall estimation results. Nonetheless, the cannabis use effects are very similar to the estimates in which we did include

[17]In this restricted model, which treats cannabis use as exogenous, cannabis use of found to significantly reduce mental health of men and women and the physical health of men. The magnitude of the estimated effects of cannabis use on the two dimensions of health are similar to those reported in 3.

[18]Due to the age composition of our sample there are only a few observations of individuals starting to use cannabis before the year 1967 and after the year 1984. Our calendar time specification allows every year between 1967 and 1984 to have a different effect on the cannabis uptake rate. For the years beyond 1984 we included a single dummy variable. Thus we added 19 parameters in the cannabis starting rates.

educational attainment.

We also investigate whether there is heterogeneity in the effect of cannabis use with respect to the respondents age at survey. We distinguish between young and old individuals where we define old to be those aged at least 36 years when surveyed in 1994. We might expect stronger health effects of cannabis use for the older group as they have had a greater amount of time for effects to have accumulated. This is similar to the idea that harm accumulates with duration of use. The older age group have an average duration of use of 13.4 years compared to 8.7 for the younger group. Panel i of Table 5 shows the relevant parameter estimates. For males do we find cannabis use has a significant negative effect on both physical and mental health for the older age group but no significant effect for the younger age group. For women, we find significant physical health effects of cannabis for the older group but not the younger group, while for metal health we find significant effects for the younger group only. However, the coefficients for both males and females are imprecisely estimated. As shown by the LR statistic in the bottom row of this panel, we are unable to reject the null hypothesis that the effects for those young and old at the time of survey are equal.

Our final sensitivity analysis examines the robustness of our results to the use of functional form assumptions to identify the causal effect of cannabis use on health. In order to relax this assumption, we require a variable that determines cannabis use dynamics but can be validly excluded from the health equations. We propose that parental cannabis use is such a variable. Specifically, we assume that parental cannabis use may affect the uptake and quitting of use by sample members but it does not have a direct effect on their current health status. Panel j of Table 5 shows the parameter estimates of the model that includes parental cannabis use in the cannabis uptake rate and the cannabis quit rate. Clearly, this has a significant effect on the overall estimation results, but it only has a very small effect on the relevant parameter estimates.

4 Conclusions

The insights from this paper address three significant issues not previously addressed. First, this research explores the impact of cannabis use on both physical health and mental health, accounting for the potential for shared frailties across these two domains of health and selection into cannabis use. Second, it provides the first evidence on the health impacts of cannabis use that are free from the confounding with the physical and psychological health effects of engaging in criminal activity. And third, this paper explores a rich set of dimensions of cannabis use including the duration of use amongst current users and duration of use amongst past users in assessing the health effects of cannabis.

Our empirical framework uses the discrete factor approach to account for unobserved common confounders linking cannabis use and health and to account for shared frailties in physical and mental health. We find evidence that individuals differ in unobserved ways in terms of their vulnerability to starting and stopping cannabis use and in their unobserved mental and physical health frailties. Moreover, the unobserved characteristics impacting on cannabis dynamics and health are found to be correlated for males. However, after accounting for endogenous selection, cannabis use is still found to have a direct negative effect on the mental health of men and women and the physical health of men.

There are several caveats to bear in mind when considering the findings of this research. First, we use retrospectively reported information on the age at which individuals started and stopped using cannabis and this information may be subject to recall errors. The likely impact of these errors is to bias the estimated effect of cannabis use on health towards zero. For this reason, we could underestimate the health effects of cannabis use. However, we could also overestimate the causal effects of cannabis use on health as our data do not allow us to address possible reverse causality, i.e. health problems leading to cannabis use. Therefore, some reverse causality may be "absorbed" in our estimated effects of cannabis use on health status.

A further reason for caution is that our results indicate that past and current cannabis use have statistically indistinguishable effects on health. In addition to expecting the health effects of current cannabis use to be greater than the effects of past use, one would also reasonably conjecture that the effects of cannabis use accumulate with duration of use and that the effects of past use fade over time. While each of these hypotheses were investigated, we were unable to find any evidence in support of them. This would seem to reflect limitations in our data's ability to make these distinctions rather than providing evidence of a lack of differential effects. Nonetheless, the data do provide robust evidence that cannabis use reduces the mental wellbeing of men and women and the physical wellbeing of men.

An important question is whether we should care about the negative health effects of cannabis use. In order to answer this question, we compare the size of the health effects we find for cannabis use with the size effects reported in the literature for having a single chronic condition or suffering a migraine. Doing so reveals that although statistically significant, the effects of cannabis use on health we estimate are small. This seems reasonable given that the estimates represent an average over all types of users: past, current, long duration, short duration, high intensity, low intensity, and various combination of these types. Nonetheless, the estimates are useful in that they suggest that for those who are not long term heavy users of cannabis, the physical and mental health effects of their cannabis use are likely to be small.

References

- Abraham, M.D., H. L. Kaal, and P.D.A. Cohen (2003) *Licit and Illicit Drug Use in Amsterdam: 1987-2001*, Amsterdam, CEDRO, University of Amsterdam.

- Aneshensel, C.S, R.R. Frerichs, and G.J. Huba (1984) Depression and physical illness: A multiwave, nonrecursive causal model. *Journal of Health and Social Behavior*, 25, 350-371.

- Aaronson, N., Muller, M., Cohen, P., Essink-Bot, M., Fekkes, M., Sanderman, R., Sprangers, M., Velde, M., and E. Verrips (1998) Translation, validation, and norming of the Dutch SF-36 Health Survey in community and chronic disease populations. *Journal of Clinical Epidemiology*, 51, 1055-1068.

- Boekhout van Solinge, T. (1999) Dutch drug policy in a European context, *Journal of Drug Issues*, 29, 511–528.

- Hall, W., Room, R, Bondy S. (1999) Comparing the health and psychological risks of alcohol, cannabis, nicotine and opiate use. In: Kalant H, Corrigal W., Hall W., and Smarts, R. (eds) *The Health Effects of Cannabis.* Toronto: Addiction Research Foundation, 1999.

- Hall, W. and R.L. Pacula (2003) *Cannabis Use and Dependence: Public Health and Public Policy*, Cambridge University Press Melbourne, Australia.

- Heckman, J.J. and B. Singer (1984) A method for minimizing the impact of distributional assumptions in econometric models for duration data, *Econometrica*, 52, 271–320.

- Korf, D.J. (2002) Dutch coffee shops and trends in cannabis use, *Addictive Behaviors*, 27, 851-866.

- The Lancet Editorial (1995) Deglamorising cannabis, *Lancet*, 346, 1241.

- Macleod, J.,R. Oakes, A. Copello, I. Crome, M. Egger and M. Hickman T. Oppenkowski, H. Stokes-Lampard and G.D. Smith (2004) Psychological and social sequelae of cannabis and other illicit drug use by young people: a systematic review of longitudinal, general population studies, *Lancet*, 363, 1579–1588.

- Moore, T., S. Zammit, A. Lingford-Huges, T. Barnes, P. Jones, M. Burke, and G. Lewis (2007) Cannabis use and risk of psychotic or affective mental health outcomes: a systematic review, *Lancet*, 370, 319–328.

- Mroz, T.A. (1999) Discrete factor approximations in simultaneous equation models: estimating the impact of a dummy endogenous variable on a continuous outcome, *Journal of Econometrics*, 92, 233–274.

- Nutt, D.J., L.A. King, W. Saulsbury and C. Blakemore (2007) Developing a rational scale for assessing the risks of drugs of potential misuse, *Lancet*, 369, 1047-1053.

- Nutt, D.J., L.A. King, and L. Phillips (2010) Drug harms in the UK: a multicriteria decision analysis, *Lancet*, 376, 1558-1565.
- Orphanides, A. and D. Zervos (1995) Rational addiction with learning and regret, *Journal of Political Economy*, 103, 739–758.
- Pacula, R. (2010) Examining the impact of Marijuana legalization on harms associated with Marijuana use, Santa Monica, *RAND Working Paper*, WR 769-RC.
- Pudney, S. (2010) Drugs policy – what should we do about cannabis? *Economic Policy*, 61, 165–211.
- Sandwijk, J.P., Cohen, P.D., Musterd, S. and Langemeijer, M.P (1995) *Licit and Illicit Drug use in Amsterdam II. Report of a household survey in 1994 on the prevalence of drug use among the population of 12 years and over*, Amsterdam, Instituut voor Scoiale Geografie, University of Amsterdam.
- UNODC (2005) *World Drugs Report*, New York: United Nations Publications.
- Van Ours, J.C. (2006) Dynamics in the use of drugs, *Health Economics*, 15, 1283–1294.
- Van Ours, J.C. and J. Williams (2007) Cannabis prices and dynamics of cannabis use, *Journal of Health Economics*, 26, 578–596.
- Van Ours, J.C. and J. Williams (2009) Why parents worry: initiation into cannabis use and their educational attainment, *Journal of Health Economics*, 28, 132-142.
- Van Ours, J.C. and J. Williams (2011) Cannabis use and mental health problems, *Journal of Applied Econometrics*, forthcoming.
- Williams, J. and C.L. Skeels (2006) The impact of cannabis use on health. *De Economist* 154, 517–546.

Appendix: Variables used in the analysis

A1: Personal characteristics

- Age: Age of individuals at the time of the survey.
- Secondary education: Dummy variable with value 1 if the individual attended secondary general or vocational education, and value 0 otherwise. Secondary education refers to intermediate vocational or secondary general education.
- Tertiary education: Dummy variable with value 1 if the individual attended higher vocational or academic education, and value 0 otherwise. Since there are three dummy variables for education the overall reference group consists of individuals with only basic education.
- Born 1950s (1960s): Dummy variable with value 1 if the individual was born in the 1950s (1960s).
- Single: Dummy variable with value 1 if the individual is living alone and value 0 if the individual is part of a multi-person household.
- Children: Dummy variable with value 1 if the individual has children and value 0 otherwise.

A2: Physical and mental health

Part of the SF-36 questionnaire is used to establish individual health situations. We use two SF-36 scales which represent physical health (Physical Functioning) and mental health. The SF-36 Physical Health scale is based on the answers to 10 questions, the SF-36 Mental Health scale is based on the answers to 5 questions. Both scales are normalized separately both for the males as well as the females in our sample such that the means are equal to 50 and the standard deviations are equal to 10. Figure 2 gives a graphical representation of the distribution of both health indicators in our samples. These distributions are discussed in more detail in the main text.

A3: Cannabis use

The information concerning the age of onset is based on the question addressed to individuals who indicated previous use of particular drug (for example cannabis): "At what age did you start using cannabis?". The information concerning the quit age is based on the question addressed to individuals who indicated previous use of a particular drug but not current use: "At what age did you use cannabis for the last time?" The duration of use is calculated as the difference between the quit age and the starting age. Current use of cannabis is defined as last year prevalence; past use of cannabis is defined as life time prevalence but no use in the last year.

Table 1: **Characteristics of the dataset**[a)]

a. Means of variables

	Men			Women		
	Mean	Min	Max	Mean	Min	Max
Mental health[b)]	50.0	8.2	63.8	50.0	13.0	64.8
Physical health[b)]	50.0	-19.3	54.4	50.0	-1.2	55.8
Age	36.4	26	50	36.7	26	50
Born 1950s	0.37	0	1	0.38	0	1
Born 1960s	0.45	0	1	0.43	0	1
Single	0.39	0	1	0.43	0	1
Children	0.31	0	1	0.41	0	1
Secondary education	0.28	0	1	0.23	0	1
Tertiary education	0.43	0	1	0.47	0	1
Past cannabis use	0.28	0	1	0.32	0	1
Current cannabis use	0.21	0	1	0.09	0	1
of which:						
Last year – not last month	0.07	0	1	0.03	0	1
Last month	0.14	0	1	0.06	0	1
Starting age[c)]	19.5	12	45	19.7	12	46
Duration of cannabis use[c)]	11.0	1	33	8.3	0	31
Cannabis use parents	0.04	0	1	0.05	0	1
Tobacco	0.75	0	1	0.75	0	1
Cocaine	0.15	0	1	0.10	0	1

b. Health scores by cannabis use status

	Never Used	**Past User**	**Current User**
Males			
Physical health	49.8	50.8	49.5
Mental health	51.9	48.8	46.8
Females			
Physical health	49.2	51.4	50.3
Mental health	50.8	49.6	46.0

[a)] Based on 818 men and 870 women (except for Starting age and Duration variables).
[b)] Variable normalized to means 50.0 and standard deviation 10.0.
[c)] Based on 399 men and 352 women.

Table 2: **Cannabis starting rate and quit rate**

	Men		Women	
	Start	Quit	Start	Quit
Secondary education	0.72 (3.8)**	-0.48 (1.9)*	0.76 (3.3)**	-0.41 (1.6)
Tertiary education	0.98 (5.4)**	-0.30 (1.3)	1.22 (6.8)**	-0.22 (1.1)
Born 1950s	1.36 (5.4)**	-0.45 (1.8)*	1.02 (3.8)**	0.04 (0.2)
Born 1960s	1.94 (7.7)**	-0.13 (0.5)	1.42 (5.3)**	0.39 (1.6)
Starting age/10	–	0.12 (0.5)	–	0.42 (2.2)**
Unobserved heterogeneity				
Mass point 1	-6.98 (18.9)**	-1.56 (2.2)**	-6.90 (18.3)**	-2.23 (4.0)**
Mass point 2	-4.42 (13.0)**	$-\infty$	-3.84 (6.7)**	$-\infty$
Mass point 3	$-\infty$	–	$-\infty$	–
α_1	0.05 (0.5)		0.05 (0.4)	
α_2	-1.86 (8.8)**		-2.99 (8.8)**	
Probabilities (%)				
p_1	47.6		50.0	
p_2	7.1		2.4	
p_3	45.3		47.6	
-Loglikelihood	2418.7		2370.7	

Note: Absolute t-statistics in parentheses; a ** (*) indicates significance at a 95% (90%) level. The cannabis starting rate contains 17 age categories (12-15, annually from 16-30 and 30+ years), the cannabis quit rate contains 4 duration dependence intervals (1, 2, 3-10, 10+ years).

Table 3: **Physical health and mental health**

	Men		Women	
	Physical health	Mental health	Physical health	Mental health
a. Full model				
Past cannabis use	-0.28 (0.4)	-2.61 (2.9)**	0.52 (0.7)	-1.78 (2.1)**
Current cannabis use	-0.98 (0.6)	0.18 (0.1)	-2.29 (1.2)	-0.88 (0.4)
Duration past use	-0.02 (0.2)	-0.00 (0.0)	0.01 (0.1)	0.04 (0.4)
Duration current use	-0.13 (1.5)	-0.15 (1.7)*	0.16 (1.5)	-0.18 (1.4)
Age	-0.11 (3.5)**	-0.13 (2.9)**	-0.14 (4.7)**	-0.09 (2.1)**
Secondary education	1.06 (2.0)**	-1.30 (1.7)*	1.00 (1.8)*	0.38 (0.5)
Higher education	1.55 (2.9)**	-1.46 (2.0)**	2.41 (4.8)**	0.67 (0.9)
Single	-0.57 (1.2)	-2.23 (3.7)**	0.48 (1.0)	-2.71 (4.2)**
Children	-0.05 (0.1)	1.39 (2.0)**	1.61 (3.6)**	1.19 (1.8)*
σ	5.44 (49.4)**	6.09 (28.8)**	5.34 (42.6)**	6.81 (25.2)**
Unobs. heterogeneity				
Masspoint 1	55.55 (40.1)**	61.34 (34.2)**	55.40 (41.3)**	57.74 (32.2)**
Masspoint 2	18.27 (13.4)**	44.05 (22.4)**	27.63 (21.1)**	40.05 (20.4)**
α_1	2.89 (12.4)**		2.74 (12.4)**	
α_2	-1.63 (2.8)**		-0.11 (0.4)	
α_3	1.54 (6.4)**		1.04 (4.5)**	
Probabilities (%)				
p_1	75.4		76.6	
p_2	0.8		4.4	
p_3	19.6		14.0	
p_4	4.2		5.0	
-Loglikelihood	5628.3		6093.8	
b. No effect duration cannabis use				
Past cannabis use	-0.43 (0.8)	-2.64 (4.0)**	0.60 (1.1)	-1.54 (2.3)**
Current cannabis use	-1.28 (2.2)**	-2.41 (3.3)**	0.50 (0.5)	-3.59 (3.3)**
-Loglikelihood	5631.4		6095.8	
LR test b–a	6.2		4.0	
c. Equal effects past and current cannabis use				
Cannabis use	-0.75 (1.7)*	-2.54 (4.5)**	0.57 (1.2)	-1.94 (3.1)**
-Loglikelihood	5632.4		6097.4	
LR test c–b	2.1		3.2	

Note: Absolute t-statistics in parentheses; a ** (*) indicates significance at a 95% (90%) level.

Table 4: **Joint estimates of cannabis starting rate, cannabis quit rate, physical health and mental health**

	Men		Women	
	Physical health	Mental health	Physical health	Mental health
a. Full model				
Past cannabis use	-0.40 (0.5)	-1.72 (1.7)*	0.48 (0.6)	-1.63 (1.6)
Current cannabis use	0.83 (0.4)	0.86 (0.4)	-2.26 (1.1)	-0.61 (0.2)
Duration past use	-0.01 (0.2)	-0.00 (0.0)	0.01 (0.1)	0.04 (0.4)
Duration current use	-0.12 (1.3)	-0.11 (1.1)	0.16 (1.4)	-0.18 (1.3)
-Loglikelihood	8031.1		8463.2	
b. No effect duration cannabis use				
Past cannabis use	-0.52 (1.0)	-1.82 (2.5)**	0.56 (1.0)	-1.38 (1.7)*
Current cannabis use	-1.33 (2.2)**	-1.02 (1.3)	0.50 (0.5)	-2.95 (2.3)**
-Loglikelihood	8033.2		8465.2	
LR test b–a	4.2		3.9	
c. Equal effects past and current cannabis use				
Cannabis use	-0.85 (1.8)*	-1.44 (2.3)**	0.55 (1.1)	-1.54 (2.0)**
-Loglikelihood	8034.6		8465.7	
LR test c–b	2.8		1.1	
LR test independence[a)]	33.0**		4.8	

[a)] Comparing the likelihood values of Tables 2a + 3c and 4c.

Unobserved heterogeneity model c.	Men	Women
α_1	2.85 (9.1)**	2.70 (7.6)**
α_2	0.30 (0.7)	-0.91 (1.4)
α_3	2.88 (9.3)**	2.66 (7.9)**
α_4	-3.01 (1.0)	-0.21 (0.4)
α_5	$-\infty$ (–)	-3.10 (2.3)**
α_6	-1.00 (1.6)	-0.10 (0.2)
α_7	1.58 (4.6)**	1.11 (2.7)**
α_8	0.37 (0.9)	-1.13 (1.6)
α_9	0.75 (1.9)*	0.88 (2.4)**
α_{10}	-0.65 (1.0)	-0.19 (0.4)
α_{11}	-1.07 (2.0)**	-1.94 (2.6)**

Distribution of unobserved heterogeneity model c.

Mental health Physical health	Good Good	Good Bad	Bad Good	Bad Bad	Total
Men					
Cannabis use type 1	36.7	0.1	10.3	1.1	48.2
Cannabis use type 2	2.9	0.0	3.1	0.7	6.7
Cannabis use type 3	37.7	0.8	4.5	2.1	45.1
Total	77.3	0.9	17.9	3.9	100.0
Women					
Cannabis use type 1	38.0	2.1	7.8	2.1	50.0
Cannabis use type 2	1.0	0.1	0.8	0.4	2.3
Cannabis use type 3	36.6	2.3	6.2	2.6	47.7
Total	75.6	4.5	14.8	5.1	100.0

Note: The table only reports the effects of cannabis use variables on physical and mental health and for panel c the parameters of the distribution of unobserved heterogeneity. Otherwise, the estimates contain the same variables as Tables 2 and 3. Absolute t-statistics in parentheses; a ** (*) indicates significance at a 95% (90%) level.

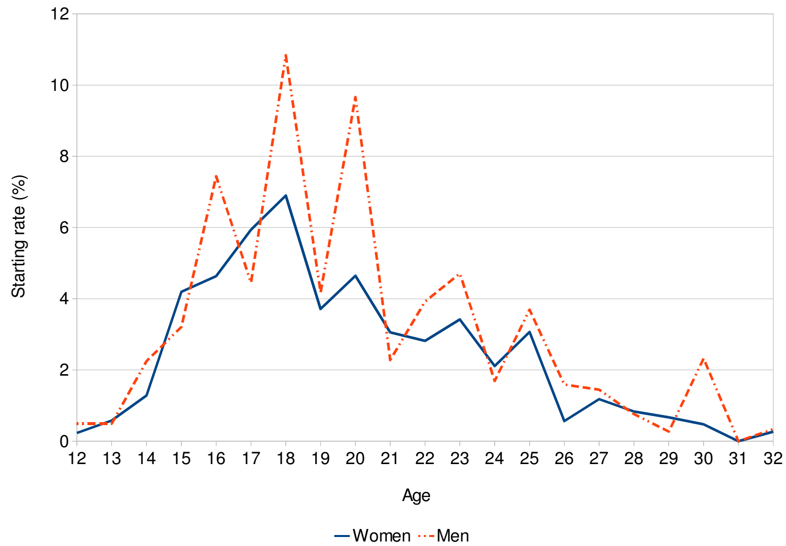
Table 5: **Sensitivity analysis effects cannabis use on physical and mental health**

	Men		Women	
	Physical health	Mental health	Physical health	Mental health
a. Baseline model				
Cannabis use	-0.85 (1.8)*	-1.44 (2.3)**	0.55 (1.1)	-1.54 (2.0)**
-Loglikelihood	8034.6		8465.7	
b. Adding last month cannabis use				
Cannabis use	-0.48 (0.9)	-1.30 (1.9)*	0.69 (1.3)	-1.54 (2.0)*
Last month use	-1.24 (1.7)*	-0.33 (0.3)	-0.90 (0.8)	0.04 (0.0)
LR test b–a	3.3		1.1	
c. Including cocaine use				
Cannabis use	-0.52 (1.0)	-1.38 (2.0)**	0.28 (0.5)	-1.22 (1.5)
Cocaine use	-1.19 (1.6)	-0.24 (0.3)	1.22 (1.1)	-1.20 (1.1)
LR test c–a	3.6		4.3	
d. Including tobacco use				
Cannabis use	-0.73 (1.4)	-1.24 (1.8)*	0.58 (1.0)	-0.72 (0.9)
Tobacco use	-0.43 (0.7)	-0.41 (0.6)	-0.11 (0.2)	-1.97 (2.6)**
LR test d–a	1.1		7.7**	
e. Including tobacco use, selection through tobacco				
Cannabis use	-0.58 (1.2)	-2.74 (4.3)**	0.63 (1.1)	-1.11 (1.6)
Tobacco use	-0.50 (0.8)	0.92 (1.2)	-0.08 (0.2)	-1.30 (1.6)
f. Including tobacco use, selection through tobacco				
Cannabis use	-0.75 (1.7)*	-2.43 (4.2)**	0.60 (1.2)	-1.50 (2.3)**
LR test e–f	2.6		2.6	
g. Flexible calendar time				
Cannabis use	-0.83 (1.8)*	-1.39 (2.1)**	0.54 (1.1)	-1.46 (1.9)*
LR test g–a	58.6**		38.8**	
h. No education in cannabis dynamics				
Cannabis use	-0.88 (1.9)*	-1.54 (2.4)**	0.51 (1.0)	-1.84 (2.4)**
LR test h–a	16.2**		17.6**	
i. Heterogeneous effects young & old				
Cannabis use young	-0.30 (0.4)	-1.05 (1.2)	0.08 (0.1)	-2.00 (2.2)**
Cannabis use old	-1.29 (2.5)**	-1.80 (2.4)**	1.10 (1.7)*	-0.98 (1.0)
LR test i–a	2.5		2.6	
j. Parental cannabis use included				
Cannabis use	-0.84 (1.8)*	-1.39 (2.2)**	0.58 (1.1)	-1.46 (2.1)**
LR test j–a	30.0**		45.6**	

Note: See footnote Table 4; note that panel 5a is equivalent to Table 4 panel c.

Figure 1: **Starting rates and quit rates cannabis use; women and men**

a. Starting rates



b. Quit rates

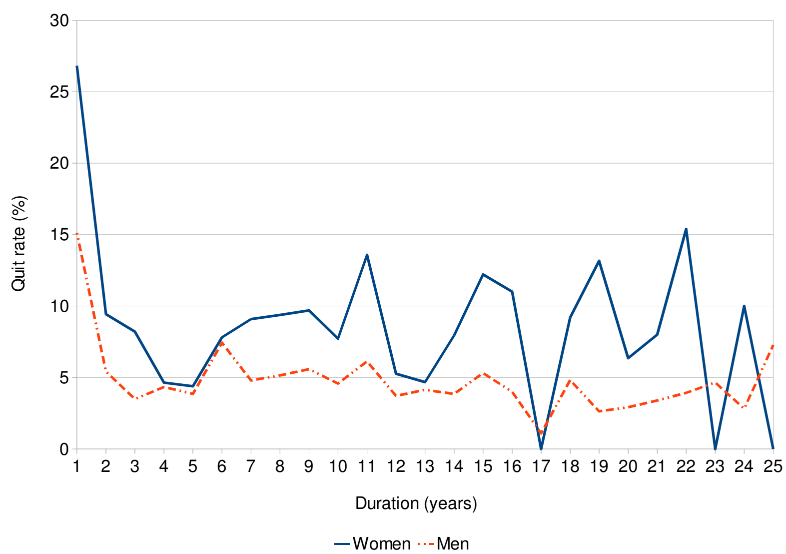
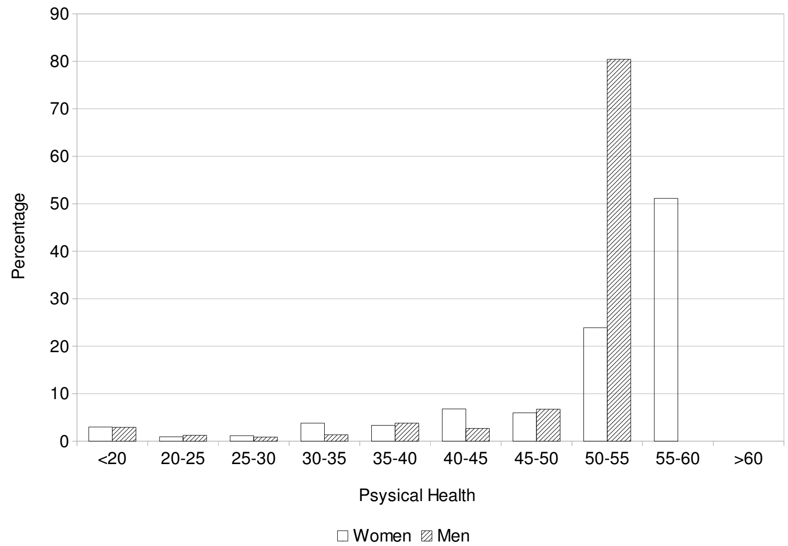


Figure 2: **Distributions of physical and mental health; women and men**

a. Physical health



b. Mental health