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DISCUSSION PAPERS

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Should We Brush Twice a Day?

Determinants of dental health among young adults in Finland

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Abstract

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We explore the determinants of dental ill-health as measured by the occurrence of caries. A recursive bivariate probit model that was derived from health production and demand theory is employed to model caries, while taking account of dental care use. The data are from a follow-up questionnaire used in a longitudinal study of the Northern Finland 1966 Birth Cohort, with respondents aged 31 (n=5020). The factors controlled for relate to family background and health behavior during their youth, current socioecononomic variables and dental health stock. The total effects on the occurrence of caries of the explanatory variables are computed.

Among females, factors increasing caries are body mass index and intake of alcohol, sugar and soft drinks, and those reducing caries are birth weight and adolescent school achievement. Among males, caries is positively related to the metropolitan residence and negatively related to education and healthy diet. Smoking increases caries, whereas dental care use, regular dental attendance and brushing teeth at least twice a day decrease caries. To promote oral health, attention should focus on policies to improve dental health education and to reduce the impacts of common risk factors.

Keywords. Demand for dental health, health production function, dental care, determinants of dental health, recursive bivariate probit
JEL. I12, I18, C35, C15

Contents

INTRODUCTION

Dental caries is largely a behavioral disease that results from particular lifestyle choices, health behavior and inadequate or absence of dental care. In various studies, caries has been found to be significantly associated with socioeconomic and behavioral factors [1–8]. However, the majority of these studies are social and epidemiologic, while only a very few of them are economic. In the latter, the determinants of dental health, i.e. caries, are simply investigated on the basis of the estimation of reduced-form equations, using typical data sets that generally have health information limited to one period of time. In addition, dental care utilization is often not taken into account in the production function of dental health as a health input. Even if utilization is treated as an explanatory variable in the production of dental health, the effects on utilization of covariates like dental health stock, individual characteristics and supply-side factors that are transmitted back to dental health is not examined or elicited at all. Further, the measurable total effects that lifestyle, health behavior, and utilization simultaneously, both directly and indirectly, have on dental health are not estimated. Both direct and indirect effects are useful measures to assess whether oral health could be promoted and improved by increasing general formal education or by interventions like targeted dental health education via health-enhancing behavior and lifestyle choices.

In Finland, prevention-oriented primary oral health care in municipal health centers has been available free of charge to all children since the 1970s, and subsidized dental care for young adults in both public and private dental sectors has been gradually expanded since 1986. Recently, Finland has achieved one of the lowest levels of the mean number of decayed, missing or filled teeth (hereafter DMFT) among developed countries for children aged 12 [9]. The proportion of 12-year-old children without dental caries increased from 1% in 1976 to 30% in 1991, while no regional differences in their dental health were found [10]. The dentist to population ratio almost doubled between 1965 and 1996 [11]. As suggested by these factors, it could be expected that those Finns who were born in the mid-1960s would be a homogenous group in respect of oral health in early adulthood (e.g. 1990s) and that at this point of their adulthood there would be a low prevalence of dental caries.

The aim of this study is to investigate the determinants of dental ill-health with a focus on caries, taking into account dental care use. We develop a recursive bivariate probit model consisting of a production function of dental health and a demand function of dental care. We jointly estimate the demand for dental care and the subsequent demand for dental health. The data are from the follow-up study of 1997–1998 included in the longitudinal study of the Northern Finland 1966 Birth Cohort. Having measured the direct effects of dental health inputs, lifestyle choices and other control variables on dental health and the corresponding direct effects of the covariates on dental care use, we estimate the total effects on dental health of all explanatory variables used in the recursive bivariate probit model. This study approach has not been applied in any earlier study of the demand for dental health. Our study also contributes to a better understanding of the link between dental health and utilization as well as the association between dental health and education over the life cycle.

THE FINNISH INSTITUTIONAL CONTEXT

In Finland, local authorities (municipalities) are responsible for arranging primary health care services for their residents through the operation of health centers. Public health services are financed by municipal taxes, state subsidies and user charges. They are supplemented by private health services, which are partly reimbursed by National Health Insurance (NHI). Oral health services are provided by both private and public dental sectors, with overall, half and half the number of dentists serving each sector. Private-sector dentists work on a fee-for-service basis, while public-sector dentists usually have a fixed monthly salary [12].

In the development of oral health services in Finland, top priority has always been given to children and adolescents. After the implementation of the Primary Health Care Act in 1972, children under 17 years received public dental care free of charge. In 1986, subsidized municipal dental care was, as per statute, only given to those born in 1961 or later, while in 1991 it was extended to those born in 1956 or later. These young adults could also use private dentist services and then claim a reimbursement from the NHI.

Child health clinics serve families with children under school age. When children start school at age seven, their health up to age 18 is taken over by the school health care system. As a part of school health care, municipal dental care is available free of charge for pupils aged under 19. In the 1980s, they were recalled to check-up visits to public dentists each year. Since the 1990s, a need-based individual care interval has been applied. Currently, pupils have their own recall interval for preventive dental care depending on dental health status, but on average, recall takes place at least once every two years [10]. Based on the assessment of caries risks, intervals between check-up visits for young people with dental good-health are also typically two-year periods [10].

The public health centers charge users for dental services at fixed fees determined by legislation.[1] Prices for private dental services have not been regulated at all since the beginning of 1993. There is no private dental insurance. For a dental care user, private services are almost always more expensive than the comparable public services even after the NHI reimbursement. In 1996, about 20% of the population lived in municipalities where health centers provided dental services for the whole population; most of those municipalities were quite small, with a few or no private practitioners [12].

1 The central government gives recommendations on maximum user fees for dental care services, but each municipality determines its own user fees.

THEORETICAL CONSIDERATIONS

Utilization of dental services can be substantially influenced by both individuals and the providers who serve them [13]. The demand-for-health model [14, 15] has been a keystone in a number of empirical applications of demand for dental health and dental care. According to Grossman's theory, individuals demand dental care for both investment and consumption purposes. Dental care is consumed to reduce current disutility related to dental problems and oral diseases or unfavorable oral health outcomes. In addition, because dental health is considered as a durable stock that depreciates over time, consumption of dental care can also influence one's dental health capital stock, which affects future utility. Besides individual characteristics, provider characteristics like rationing in dental care and changes in the total number of dentists or other supply-side factors can also impact on the demand for and utilization of dental care.

To explore the determinants of dental health, we apply a modified model based on several theories of the household health production function [16, 17]. In this framework, an individual is assumed to seek and combine non-market and market inputs to obtain an output of better dental health. Subject to income and time constraints, s/he is supposed to select dental health behavior and lifestyle on the basis of both the direct utility effects and the health effects. By chosen dental health behaviors and lifestyle inputs, s/he can thus also affect her/his own oral health. To investigate the determinants of dental care utilization, we use a simple theoretical model based on the theory of demand for health and dental care [13, 15, 18, 19] as described in the study [20]. The variables chosen to explore the determinants of dental health are based on the health production theory [14] and on findings from earlier studies on the factors that affect general health [16, 17, 21, 22] and dental health [3, 4, 23]. Those variables selected to investigate the determinants of dental care use are based on previous studies on health and dental care utilization [4, 15, 18–20, 24, 25].

DATA AND VARIABLE SPECIFICATIONS

Our study data are from the longitudinal study of the Northern Finland 1966 Birth Cohort (http://kelo.oulu.fi/NFBC). This unselected general population birth cohort included all live births in the provinces of Oulu and Lapland in 1966 (n=12 058), with data collected since pregnancy. Information on parental socioeconomic and demographic background was collected by questionnaires. Information on pregnancy, births and newborns at the delivery time was transcribed to study forms by midwives. Data were collected by the health workers in child health centers at age one and by adolescent questionnaires at age 14. The latest postal questionnaire study was conducted in 1997–1998 when the cohort had reached 31 years of age (n=11 541). The number of eligible replies was 8690, corresponding to a response rate of 75.3%.

The empirical analysis is based on a sample drawn from the latest follow-up study (n=5020) with information of the past linked to data from the mentioned longitudinal study. Attrition considerably minimized the original study population (Appendix 1). According to an analysis of sample selection, the proportion of cases left out of the latest questionnaire study was higher among males (59% of male cases) than among females (52% of female cases), and the probability of being included in the study was positively associated with education (see [26], Appendix A).

The dependent variables are based on the 1997 follow-up study. The dependent variable in the dental health production function, *caries*, measures the probability of having caries at the time the questionnaire was completed. This dental health was determined by a question with two response alternatives (no/yes): "In your opinion, do you have caries in your teeth at this moment?". Because the total number of visits to dentists (hereafter *dental visits*) during a period of time is a discrete and non-negative integer and dental visits have different values as each visit generally carries a different mix of care services, we consider *visit*—the probability of having at least one dental visit—to be a measure of dental care utilization during the year previous to the data collection time (Appendix 2). The probability of having caries among those who had no dental visit was approximately 43%, whereas the corresponding figure among those who had at least one dental visit was only 26% (Table 1).

TABLE 1. Caries and visits to dentists: Frequency distributions in the sample (n=5020)

	Females			Males		
	Non-caries	Caries	Total	Non-caries	Caries	Total
No visit	652	388	1040	640	601	1241
At least one visit	1248	395	1643	781	315	1096
Total	1900	783	2683	1421	916	2337

Data on the mean scores of all school subjects completed at the end of compulsory school were collected at age 16. Data on the highest levels of education completed by age 31 were gathered from the National Education Registry of Statistics Finland by means of official personal identification numbers, on the basis of which the number of years of schooling is computed. The income measure is self-reported family gross income that takes into account the family structure, using an OECD equivalence scale. This gives a weight of 1 to the first adult, 0.7 to the second adult, and 0.5 to each child in the household. A log transformation of equivalized income is used to smooth out the extreme values in its distribution. Information on the population and the number of dentists in health center districts was gathered from several official registers and statistics.

TABLE 2. Descriptive statistics – Means and standard deviations of the variables

Variable	*A priori* expectation[a]			Females		Males	
	Direct effect		Total effect	(n=2683)		(n=2337)	
	Caries (Eq. 1)	*Visit* (Eq. 2)	on *Caries*	Mean	S. D.	Mean	S. D.
Dependent variables							
caries				0.29	0.45	0.39	0.49
visit				0.61	0.49	0.47	0.50
Independent variables							
Variables relating to the birth time							
bweight[b]	–		–	3.45	0.49	3.57	0.53
bmschool[b]	–		–	6.73	2.29	6.76	2.39
bmsmoke	+		+	0.18	0.39	0.19	0.39
brural	+		+	0.68	0.47	0.67	0.47
Variables relating to the youth time							
y14fses1	–		–	0.13	0.33	0.14	0.34
y14fses2	–		–	0.20	0.40	0.19	0.39
y14fses3[#]				0.68	0.47	0.67	0.47
y14fsmok	+		+	0.35	0.48	0.36	0.48
y14smoke	+		+	0.06	0.24	0.05	0.23
y14alco	+		+	0.03	0.16	0.01	0.12
y14sport[b]	–		–	9.36	9.59	13.90	10.62
y14score[b]	–		–	8.01	0.84	7.39	0.87
y14illmi	+		+	0.14	0.35	0.14	0.35
y14illgr	+		+	0.11	0.31	0.10	0.31
Health and dental health behavior at the age of 31							
alco[b]	+		+	5.28	8.98	13.24	17.87
sport[b]	–		–	28.84	33.60	33.58	39.60
bm[b]	+		+	23.58	4.20	25.16	3.36
smokedly	+		+	0.17	0.38	0.28	0.45
dietgood	–		–	0.47	0.50	0.20	0.40
sugar	+		+	0.47	0.50	0.69	0.46
softd	+		+	0.05	0.22	0.13	0.33
canchoc	+		+	0.13	0.34	0.07	0.26
brushing	–		–	0.69	0.46	0.41	0.49
nadult[b]	+/–		+/–	1.80	0.50	1.83	0.52
nchild[b]	+/–		+/–	1.43	1.31	1.11	1.24
Individual characteristics at the age of 31							
lninc[b]	–	+	–	11.19	0.68	11.27	0.63
eduyrs[b]	–	+/–	–/+	12.46	1.95	12.10	2.12
workfull	+/–	–/+	+/–	0.50	0.50	0.69	0.46
student	+	–	+	0.04	0.20	0.03	0.18
unempl	+	–	+	0.12	0.32	0.10	0.29
occuelse[#]				0.34	0.47	0.18	0.39
metropol	–	+/–	–/+	0.16	0.36	0.13	0.33
areaelse[#]				0.84	0.36	0.87	0.33
checkreg	–	+	–	0.81	0.39	0.58	0.49
Dental health stock at the age of 31							
teeth	+	+	+	0.41	0.49	0.45	0.50
allteeth[#]				0.59	0.49	0.55	0.50
malocclu	+/–	+/–	+/–	0.16	0.37	0.13	0.33
Price of dental care and provider characteristics in the previous year							
visitime[b]		–	+	1.25	1.02	1.27	0.83
dpratio[b]		+	–	0.97	0.45	0.96	0.45
careall		+	–	0.21	0.41	0.20	0.40
Utilization of dental care during the previous year							
visit	–		–				

a The hypothetically expected directions of the direct effects of the explanatory variables on *caries* and on *visit* and those of the total effects on *caries* of all the explanatory variables used in the recursive probit model.
b These variables are/are treated as continuous variables.
\# Reference category.

Appendix 2 and Table 2 present definitions and summary statistics of the variables and theoretical directions of the effects that the independent variables have on the dependent ones. Education has been suggested as an important variable related to general attitudes toward oral health, the value of teeth, and the use of dental services [20, 27]. Women, higher-educated individuals, and people of young age presumably have a higher valuation of oral health. The negative impact of education on health (also on dental health here) occurs via two kinds of effects [22]. First, an increase in education allows an individual to obtain a better health status from a given set of health inputs. Thus, education is expected to have a negative effect on the use of health care services because people with higher education are more efficient in applying care received or improving their health through their household production or personal behavior. Second, to produce health, a more educated individual is likely to select more efficient health inputs or a better input-mix to the health production function. The first effect of education is the productive efficiency effect, and the second one is the allocative efficiency effect. The third effect of education is seen to relate to taste [16]. As higher-educated people recognize and enjoy the benefits of better dental health and have a higher valuation of oral health, they may demand more dental care. As the high valuation of oral health increases the use of dental care and the productive efficiency of education reduces it, the effect of education on use can be either positive or negative (see Table 2).

Dental health equation (caries)

Birth weight—a proxy for genetic endowments and initial health—is seen as dependent on mother's schooling (Table 2).[2] Both variables 'y14illmi' and 'y14illgr'—a proxy of general health stock in their youth—are included because illnesses of long duration may predispose people to poor dental health. Similar to education, the hypothetical effect on caries of adolescent school achievement (y14score) is negative. The variables describing general health and dental health behavior (y14alco, alco, bmsmoke, y14fsmoke, y14smoke, smokedly) may amplify caries risks, and the variables characterizing lifestyle and health habits (y14sport, sport, dietgood) presumably promote general and dental health. An ordinary 6-class variable for diet was constructed according to the questions on the consumption of food (i.e. rich in fiber or high-saturated fats) [29].

High values of body mass index (bm) indicate general poor health, whereas use of sugar in coffee and/or tea (sugar), consumption of soft drinks (softd), and intake of candies and/or chocolate (canchoc) are general indicators of poor dental health behavior. Self-care like regular tooth brushing (brushing), use of dental care (visit) and the habit of visiting a dentist regularly (hereafter *regular dental attendance*, checkreg) are supposed to control and alleviate caries. Assuming a negative association between caries and the total number of natural teeth (allteeth), we expect a positive relationship between caries and having at least one missing tooth (teeth).

Dental care equation (visit)

The number of missing teeth at age 31 (teeth) is used as a proxy for dental health at age 30 (this measurement of dental health status is discussed below). Assuming that people with a lower number of remaining natural teeth use more dental services to compensate for the decline in dental health, a positive relationship between 'visit' and 'teeth' would be expected. The effect of 'metropol' on 'visit' is undetermined because demand for dental care in the metropolitan area can increase and decrease at the same time due to the availability effect and the price effect.

2 Because defective brain functioning and abnormally low IQ's may be experienced through the lives of children who had excessively low birth weights [28], birth weight is taken into the models.

Measuring the time price of a dental visit, a longer visit time (visitime) predicts a lower demand for dental care. Owing to the availability effect, we expect both 'dpratio' and 'careall' to increase the consumption of dental care. We have no information on the reasons for using acute dental care and on the out-of-pocket payment. However, we believe that the effect of the latter variable on utilization is captured by the price and available effects of 'metropol', 'dpratio' and 'careall'. The direction of the direct effect of full-time working (workfull) on dental care use and on caries is unanticipated because we do not know which effect—the income effect or the substitution effect—is dominant.

The hypothetical effect of dental care use on caries is negative, thus possibly altering the final directions of the total effects on caries of the independent variables that are used in both equations or only in the visit equation (Table 2). For example, given that utilization is negatively associated with caries, the total effect of education on caries is not *a priori* clear because the direct effect of education on caries is decreasing but the direct effect of education on utilization can be either increasing or decreasing. Regular dental attendance directly reduces caries and increases utilization, and it ultimately decreases caries while taking into account its indirect effect on caries via utilization.

The number of missing teeth (teeth) is treated as exogenous in both *caries* and *visit* equations. 'Teeth' in the study period is free from simultaneity with past dental care utilization and thus exogenous in the visit equation (see Appendix 2; cf. [20]). Earlier research has revealed that the number of teeth is an important predictor of dental care utilization [19, 20, 25, 30]. In estimating the demand for health care, taking into account health status is assumed to enable a reduction in the possible contamination of the income variable that originates from the correlation between income and health [31]. It has been also shown that the number of natural teeth remaining is negatively related to caries [23] and both caries and the number of missing teeth are strongly associated with socioeconomic status and lifestyle [6, 7]. The number of teeth was not used in a previous study on the demand for dental health among young men due to a very low number of missing teeth [4]. Among young adults, tooth loss is the result of dental diseases and treatment decisions that are influenced by individual health habits, attitudinal factors and financial reasons. Within this 31-year-old cohort member group, the high number of missing teeth was rare. Some of them could have had extractions because of third molars, single fractures, orthodontic treatment, and accidents. Furthermore, the number of natural teeth remaining or that of missing teeth is rather stable in a number of years in the course of life, whereas caries is preventable and its effect is temporary compared to the loss of teeth. Hence, 'teeth' is assumed to be free from simultaneity with caries for the moment. However, we also tested the potential endogeneity of 'teeth' (see Estimation methods).

ECONOMETRIC SPECIFICATIONS

The econometric model

Our two-equation model of caries (dental health), *h*, and visit (dental care use), *c*, for a representative individual can be simply denoted as $h = f(x,c)$ and $c = l(g)$, where *x* stands for all exogenous variables in the caries equation and *g* stands for the exogenous variables in the visit equation (Table 2). This model assumes that dental care has an impact upon oral health but that oral health does not in turn have an influence back on dental care. The recursive specification addresses the sequential order of events of the 1997 cross-sectional data.

The bivariate probit model applies to a pair of binary dependent variables with correlated disturbances [32, 33]. In this model, each of the dependent variables is explained by a set of explanatory variables. In addition, there are omitted variables in the form of unobserved components represented by random error terms. The omitted variables could affect both of the dependent variables at the same time and therefore cause a connection between the dependent variables. Unobserved individual behavior, experience and characteristics – such as the high valuation of natural teeth and appearance, good experience from regular dental attendance during school time, dental diseases or symptoms, and provider-offered incentive like dentist's recall – are examples of factors or issues that may simultaneously influence oral health status and dental care use.

In our application, we model two sequential events and thus view *caries* (the probability of having caries) and *visit* (the probability of using dental care) as being involved in a recursive bivariate probit model. Let h_i be the probability of the individual *i*th to have caries at the data collection time and c_i be an endogenous variable representing the probability of the same individual to use dental care during the year previous to the data collection time. The endogenous observed dummy variables, h_i (having or not having caries) and c_i (using or not using dental care) are modeled as a recursive bivariate probit model based on latent variables h_i^* and c_i^*:

(1) $h_i^* = \beta' x_i + \gamma c_i + \varepsilon_i, \qquad H_i = 1 \text{ if } h_i^* > 0, \; 0 \text{ otherwise}$ [Having caries index]

(2) $c_i^* = \alpha' g_i + \mu_i, \qquad C_i = 1 \text{ if } c_i^* > 0, \; 0 \text{ otherwise}$ [Using dental care index]

where

$$\begin{pmatrix} \varepsilon_i \\ \mu_i \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix} \right).$$

The model above is estimated by full information maximum likelihood (FIML). This involves forming the joint distribution of the two random variables and then maximizing the full log likelihood function. Given the joint distribution of the error terms $(\varepsilon_i, \mu_i)'$, the joint probability of $(h_i, c_i)'$ is given by

(3) $\Pr(H_i = h_i, C_i = c_i) = \Phi_h(q_{ih} z_{ih} + \gamma c_i, q_{ic} z_{ic}, q_{ih} q_{ic} \rho)$

where $\Phi_h(.)$ refers to the bivariate normal cumulative distribution function, $q_{ih} = 2h_i - 1$,

$q_{ic} = 2c_i - 1$, $z_{ih} = \beta' x_i$ and $z_{ic} = \alpha' g_i$.

In addition to the dental care use variable that appears as an explanatory variable in the first equation, the equations of the model introduced are linked by their disturbances. The correlation coefficient ρ measures the correlation between the disturbances ε_i and μ_i in equations (1) and (2). The asymptotic *t*-ratio for the estimate of the correlation coefficient ρ provides a test for exogeneity. Under the null hypothesis of ρ=0, the recursive bivariate probit model (hereafter the *biprobit model*) turns into a recursive model of two single probit equations (hereafter the *recursive probit model*). That is, if ρ equals zero, the equations are actually unrelated by the disturbances. The log likelihood of the recursive probit model is the sum of the log likelihoods for the independent probit equations, which can be estimated separately by the maximum likelihood (ML).

Irrespective of the result of the null hypothesis of ρ, in the recursive model consisting of equations (1) and (2), an explanatory variable that is used in both equations typically has two kinds of effects on the probability of having caries: one as a direct effect produced by its presence in the first equation, and another as an indirect effect through dental care use. The total effect of an explanatory variable on the probability of having caries is the sum of these two parts. If the variable only appears on the right-hand side of the first (second) equation, its direct (indirect) effect on the probability of having caries is also its total effect.

Estimation methods

Based on theoretical and empirical studies introduced above, two sets of independent variables were first chosen from the variables available in the longitudinal study of the Northern Finland 1966 Birth Cohort. Next, by running single probit equations for the dependent variables and using procedures of step forward and step backward we selected the independent variables. Then, for the sake of parsimony we tested and decided on the final independent variables by comparing log likelihood values obtaining from several single probit equation models having different explanatory variables. Afterward, we checked multicollinearity among the selected final independent variables. For the caries equation, the VIF (variance inflation factor) values of all the variables (Table 2) and a dummy gender variable were between 1.03−2.08 with an average VIF of 1.23. For the visit equation, the corresponding figures were 1.01−1.49 and 1.19.

The problem associated with using current indicators of heath status to predict past health care utilization in cross-sectional estimation has been previously discussed (e.g. [34−36]). In this study, for testing possible endogeneity of 'teeth' in the caries equation, we applied a two-step method equivalent to the omitted variable approach of the Hausman test [37, 38]. The *teeth* equation was estimated by maximum likelihood as an independent probit model, from which residuals or predicted values were generated and then included in the right-hand side of the caries equation as a regressor [37].[3] In computation, when 'teeth' is a binary dependent variable, including residuals or including predicted values from the teeth equation to the caries equation as a new regressor results in the same coefficient estimate of the new regressor and its standard error [38]. A statistically significant non-zero coefficient of the predicted value term suggests that the suspected endogenous variable 'teeth' should be treated as endogenous. Based on this test, the coefficient for the predicted value term was not statistically significant from zero at a 5% level (t=−1.35). Since this supports our earlier exogeneity assumption of 'teeth', we treat 'teeth' as exogenous in the caries equation.

As for a possible connection between the disturbances due to the omitted factors, we ran a biprobit model for both dependent variables using the sets of explanatory variables in Table 2 and a dummy gender variable. The estimate of the disturbance correlation coefficient ρ in the biprobit model was –0.5066, with a standard error of 0.2763. For testing the null hypothesis that

3 In the teeth equation, we used a dummy gender variable and all independent variables except 'nchild', while in the caries equation, we used a dummy gender variable and all independent variables except 'malocclu' (Table 2).

ρ equals zero, the likelihood ratio statistic was 2.229 (p=0.136) and the Wald statistic was 3.364 (p=0.067) for a chi-square with one degree of freedom (Appendix 3). Since the null hypothesis of a zero correlation coefficient could not be rejected, we applied the recursive probit model.[4] Thus, the model consists of equation (1)–(2) with correlation ρ=0.

Gender has been found to be strongly associated with dental health measured as the DMFT levels, with dental health behavior and the use of dental services [20, 24, 39–41]. Being aware of these, we carried out Chow-type tests on the coefficient parameter homogeneity between females and males for the recursive probit model. Although the test results confirmed splitting the total sample into subsamples of females and males for *visit* (p=0.014), they only provided weak support for dividing the total sample by gender for the recursive probit model (p=0.053) (Appendix 4). However, our dummy gender variable test for *caries* pointed out that gender differences are significantly related to two factors, education (eduyrs) and having at least one missing tooth (teeth): both the direct decreasing effect of *eduyrs* and the direct increasing effect of *teeth* on the probability of having caries are essentially higher for males than for females. Because these variables are also used to explain *visit*, which in turn influences *caries* as a dental health input, their effects on *visit* are transmitted back to *caries*. Hence, their total effects on *caries* are affected to some extent through the impact of *visit* on *caries*. Due to this interconnection and so as to compare results between females and males easily, we decided to estimate the models separately for each gender.

Lastly, both estimated models were subjected to a RESET-type test as a simple check of adequacy. The Ramsey RESET test [42] checks the misspecification of a linear regression model by means of an augmented regression, $y_i = \delta' v_i + \lambda' w_i + \xi_i$, where $\lambda' w_i$ is a set of test regressors and w_i contains powers of the predicted values of the dependent variable. The test for specification error is then $\lambda' = 0$. To implement a RESET-type test for the recursive probit model applied here, one common way is that a second power of the estimated linear predictor of the dependent variable is added as an auxiliary regressor in the corresponding equation, which is then run again. The null hypothesis of no misspecification is rejected if the new coefficient is statistically significant. Based on this test, for females the null hypothesis that the recursive probit model is well specified was obviously supported (p=0.136 for *caries*; p=0.895 for *visit*). However, for males the analogous null hypothesis was rejected for *caries* (p=0.003) but was accepted for *visit* (p=0.087). Hence, the current model specification is more adequate for the sample of females than for that of males.

As described, for endogeneity relating to the connection between dental care consumed and the resulting dental health, we have explicitly modeled the dental care process as an integrated part of the recursive probit model. The study of Häkkinen et al. [26], in which the same longitudinal data are used, indicates that endogeneity is mostly involved in the individual lifestyle choices, via which general health is influenced. It is also possible that in our study dental health behavior variables are connected to education. A model that simultaneously allows for endogeneity of both dental care use and education would be much more complex to estimate. However, at present, we are only interested in the link between dental caries and dental care use and thus in the total effects on the prevalence of caries of the covariates used in the two-equation model. Therefore, endogeneity other than the mentioned linkage have not been taken into consideration in the recursive probit model.

The models were estimated by the Stata 8 package [43]. The estimation results are presented as elasticities for the continuous explanatory variables and as percentage changes for the dummy

4 By definition, the correlation coefficient ρ measures the correlation between the disturbances in the equations, i.e. the omitted factors. In our present model, ρ roughly measures the correlation between the outcomes – caries and visit – after the influence of the included variables is accounted for. That is, the value of ρ (–0.5066) measures the effect after the influence of 'visit' is already accounted for. If 'visit' does not appear on the right-hand side of the caries equation, other variables being the same, the estimate of ρ in the biprobit model is –0.2111. The likelihood ratio statistic for testing the null hypothesis that ρ equals zero is $\chi^2(1)$ = 72.80 (p=0.000), so the hypothesis cannot be rejected.

ones. The latter indicate the way in which a change in a certain dummy explanatory variable's value from 0 to 1 affects the dependent variable, all other things being equal. The effects were first computed for each observation in each subsample and then the individual effects were averaged. The methods for calculating the marginal and total effects of the explanatory variables used in the recursive probit model are provided and described further in Appendix 5. In addition, the standard errors of the total effects on the occurrence of caries of the explanatory variables were calculated using a non-parametric bootstrapping simulation technique [44], where the whole model was fitted for 10 000 bootstrap replicates of the original data.

RESULTS

The estimation results from both the recursive probit models are presented in Table 3. The goodness-of-fit values (pseudo-R^2) vary between 0.086 and 0.105 for the caries equations and between 0.069 and 0.118 for the visit equations. The pseudo-R^2 values are to some extent higher for the recursive model of males. Both models are significant, and they correctly predict 68–73% of observations. However, the caries equations correctly classify caries (63%) worse than non-caries (75% for females; 70% for males). Most of the elasticities and the %-changes measuring the direct effects of the covariates have the expected sign. A few of those having the unexpected sign are not statistically significant at a 5% level with the exception of visit time (visitime) in the recursive model of females. Visit time has an increasing direct effect on dental care use (visit), through which it reduces caries.

Regarding simply the direct effects, among females the probability of having caries is negatively associated with regular dental attendance (checkreg), dental care use, regular tooth brushing (brushing), adolescent school achievement (y14score), and birth weight (bweight), and it is positively associated with the intake of sugar (sugar), alcohol (alcohol) and soft drinks (softd), with daily smoking (smokedly), a body mass index (bm), and having at least one missing tooth (teeth) (Table 3). Females' dental care use is significantly increased by regular dental attendance, visit time, and having at least one missing tooth. Female full-time workers (workfull), students (student), and unemployed individuals (unempl) use dental care less than their counterparts do. According to the significant total effects, caries is negatively connected to regular dental attendance and visit time, and it is positively connected to having at least one missing tooth. The other significant total effects on caries are actually their direct effects coming straight from the caries equation.

Among males, having at least one missing tooth, daily smoking and a metropolitan domicile (metropol) directly increase the occurrence of caries, whereas dental care use, regular dental attendance, education (eduyrs), regular tooth brushing, and healthy diet (dietgood) decrease the occurrence of caries (Table 3). Males' dental care use is significantly related to regular dental attendance and having at least one missing tooth. The significant total effects on caries of the covariates—directly derived from the caries equation and/or indirectly through dental care use—indicate that the same covariates also significantly affect the occurrence of caries in the recursive probit model.

Looking briefly at the magnitude of the total effects of the covariates, we can identify the importance of using dental care to reduce caries. Compared to those non-users of dental care, the users have caries 30% (among females) and 38% (among males) less. More, for both genders, the decreasing total effect on the probability of having caries of regular dental attendance is stronger than its merely significant direct effect. Moreover, in both models, although the probability of having at least one missing tooth increases the probability of having caries and that of using dental care, its total effect is smaller than its direct effect due to the decreasing effect of dental care use on caries. Among males, because education and the metropolitan domicile have negative direct effects on dental care use, the total effect of education on the probability of having caries is absolutely smaller and that of the metropolitan domicile is higher than their respective direct effects. Among females, the total effect of visit time on caries—here only its indirect effect through dental care use—is significantly negative.

TABLE 3. Estimation results from the recursive probit models for dental ill-health (caries) and dental care use (visit)

Variable	Females						Males						
	Direct effect				Total effect		Direct effect				Total effect		
	Caries (Eq. 1)		*Visit* (Eq. 2)		on *Caries*		*Caries* (Eq. 1)		*Visit* (Eq. 2)		on *Caries*		
	Elasticity	t-ratio	Elasticity	t-ratio	Elasticity	t-ratio	Elasticity	t-ratio	Elasticity	t-ratio	Elasticity	t-ratio	
bweight	-0.551	-2.73			-0.551	-2.73	-0.072	-0.44			-0.072	-0.44	
bmschool	-0.150	-1.48			-0.150	-1.48	-0.100	-1.21			-0.100	-1.21	
y14sport	-0.007	-0.25			-0.007	-0.25	-0.015	-0.46			-0.015	-0.46	
y14score	-0.985	-2.69			-0.985	-2.69	-0.208	-0.75			-0.208	-0.75	
alco	0.044	2.63			0.044	2.63	0.032	1.63			0.032	1.63	
sport	-0.018	-0.71			-0.018	-0.71	-0.036	-1.67			-0.036	-1.67	
bm	0.455	2.81			0.455	2.81	0.199	1.08			0.199	1.08	
nadult	0.003	0.03			0.003	0.03	0.079	0.88			0.079	0.88	
nchild	0.063	1.69			0.063	1.69	0.021	0.85			0.021	0.85	
lninc	-0.048	-1.00	-0.025	-1.02	-0.044	-0.82	0.007	0.15	0.038	1.06	0.000	0.01	c
eduyrs	0.029	0.12	-0.065	-0.64	0.041	0.16	-0.589	-3.04	-0.215	-1.70	-0.551	-2.74	c
visitime			0.057	2.50	-0.010	-2.00			0.059	1.89	-0.011	-1.70	c
dpratio			-0.038	-1.04	0.007	0.99			-0.090	-1.80	0.016	1.72	c
	%-change	t-ratio	%-change	t-ratio	%-change	t-ratio	%-change	t-ratio	%-change	t-ratio	%-change	t-ratio	
bmsmoke	0.1	0.02			0.1	0.02	8.2	1.30			8.2	1.30	
brural	11.2	1.74			11.2	1.74	0.1	0.01			0.1	0.01	
y14fses1	-2.6	-0.25			-2.6	-0.25	-5.6	-0.65			-5.6	-0.65	
y14fses2	-3.4	-0.45			-3.4	-0.45	0.3	0.05			0.3	0.05	
y14fsmok	8.3	1.35			8.3	1.35	8.8	1.69			8.8	1.69	
y14smoke	14.1	1.08			14.1	1.08	-6.5	-0.57			-6.5	-0.57	
y14alco	-19.9	-1.09			-19.9	-1.09	-34.1	-1.60			-34.1	-1.60	
y14illmi	4.4	0.52			4.4	0.52	-1.7	-0.24			-1.7	-0.24	
y14illgr	-6.3	-0.69			-6.3	-0.69	-1.7	-0.21			-1.7	-0.21	
smokedly	22.9	2.73			22.9	2.73	19.7	3.35			19.7	3.35	
dietgood	-8.3	-1.40			-8.3	-1.40	-12.7	-2.00			-12.7	-2.00	
sugar	16.2	2.75			16.2	2.75	6.2	1.16			6.2	1.16	
softd	36.2	2.69			36.2	2.69	12.0	1.64			12.0	1.64	
canchoc	10.4	1.21			10.4	1.21	18.0	1.88			18.0	1.88	
brushing	-20.2	-3.10			-20.2	-3.10	-10.7	-2.03			-10.7	-2.03	
teeth	12.5	2.10	7.1	2.34	11.2	1.88	24.9	5.03	13.5	3.30	22.4	4.43	c
malocclu	1.6	0.20	-2.5	-0.61	2.0	0.25	-14.1	-1.92	-3.1	-0.51	-13.6	-1.87	c
checkreg	-63.3	-7.91	56.6	14.03	-75.2	-9.14	-34.8	-6.44	81.2	18.20	-49.8	-9.74	c
metropol	10.1	1.20	-6.2	-1.43	11.3	1.26	15.5	2.03	-7.6	-1.19	17.0	2.10	c
workfull	4.3	0.63	-10.3	-3.01	6.2	0.90	-4.7	-0.71	-3.5	-0.64	-4.0	-0.60	c
student	14.3	0.95	-24.2	-3.12	18.9	1.19	-5.9	-0.41	-15.4	-1.25	-3.3	-0.21	c
unempl	-6.6	-0.68	-12.3	-2.41	-4.5	-0.46	-7.0	-0.72	-9.0	-1.11	-5.4	-0.55	c
careall			0.6	0.15	-0.1	-0.15			-1.0	-0.17	0.2	0.17	c
visit	-30.0	-4.82			-30.0	-4.82	-38.4	-7.16			-38.4	-7.16	
–Log L			1480.6	1668.2				1400.7		1424.7			
Model	$\chi^2(34)$[a]	278.7	$\chi^2(12)$[a]	246.4			$\chi^2(34)$[a]	328.3	$\chi^2(12)$[a]	381.4			
Pseudo-R2[b]		0.086		0.069				0.105		0.118			
Correctly classified (%)		73.43		67.54				68.21		68.16			
D[d] = 0		74.62		66.87				70.11		74.78			
true D[d]		62.78		67.69				63.29		63.19			

a p=0.000.
b Pseudo-R^2 or McFadden's likelihood ratio index LRI = $1-\ln L/\ln L_0$. LnL is the maximized value of the log likelihood function for the current model, $\ln L_0$ is the log likelihood computed with only a constant term, and *n* is the sample size.
c The standard errors for these t-ratios were calculated using a bootstrapping simulation technique.
d D is the dependent variable in each probit model. True D is defined as the dependent variable being equal to 1.

DISCUSSION

The significant total effects of the covariates on caries resulting from the estimated recursive probit models are overall consistent with the predictions of our dental health production model. The gender analysis has revealed that the most apparent gender differences are largely related to formal education, adolescent school achievement, having at least one missing tooth, regular dental attendance, and regular tooth brushing. The total effects of the last two determinants on caries are in absolute values essentially higher for females than for males. In particular, among females the total effect of having at least one missing tooth on having caries is not statistically significant at a 5% level. This perhaps raises a question on whether females' habits concerning oral hygiene and regular dental attendance could protect teeth from predisposing to caries better than the corresponding habits of males.

The significant positive effect of visit time on females' dental care use seems to be contrary to what would be expected on the strength of health care demand theory. The visit time needed for a visit to the dentist varied with travel and waiting, mostly with the former, as treatment time is generally fixed and an appointment with the dentist is usually made in advance. Since our utilization measure stands for the probability of having at least one visit to the dentist during the year previous to the data collection time, the result suggests that time price was not an important barrier for females to seek care from a dentist. Further, the decreasing total effect of visit time on caries also implies that the time cost spent on a visit to the dentist could be equated to the received dental treatment that alleviates females' caries. Probably, those females experienced high levels of caries and thus a great need for dental care, but they had to travel a long distance from home to municipal health centers to receive treatment. As for the negative association of unemployment status with dental care use among females, this reveals the relatively weakened position of females in the labor market in 1997. Quite similarly, the negative effects of full-time working and student status on females' dental care use reflect their limited resources when making decisions on the consumption of dental care.

It appears that among females the intake of alcohol, sugar in coffee and/or tea and soft drinks, and a high body mass index are detrimental to dental health. Since these habits—usually associated with high values of the body mass index—have demonstrated adverse health effects, decreasing consumption of those goods and keeping control of body weight may enhance dental health. Living in the metropolitan area seems to predispose males to caries attacks more easily, which could be partly explained by the effects of unhealthy living habits in big cities on dental health. As to our finding of a positive association of daily smoking with caries, one should bear in mind that our dichotomous smoking variable is a point-in-time measure of behavior, whereas the negative impacts of smoking on periodontal diseases usually develop over long periods of time. In the course of time, that association may develop into a dental disease process, which in combination with poor oral hygiene, unhealthy behavior, and negative attitudes may eventually lead to tooth loss.

As the evidence-based preventive effect of fluoride on caries increases with the number of brushes despite results of cleanness (for example, see [45]), the amount of toothpaste used in brushing twice a day would assure a sufficient receipt of fluoride to prevent teeth from caries attacks. Compared to a single careful brushing of teeth per day, brushing with fluoride toothpaste twice a day reduces caries significantly more. This is considered as a cheap but effective way of preventing caries by the dentist profession. Regular dental attendance can prevent oral health from becoming very poor, thus bringing about high costs of treatment and also high dental care expenditure later on. In order to avoid unnecessary dental costs and for the best possible benefits

of oral health, people should be informed of the hidden benefits of regular dental attendance and be encouraged to visit the dentist for dental check-ups regularly.

We find a lower prevalence of caries associated with higher education only among males. This result indicates, though only in part, the impact of education on dental health in a promoting way, which supports the hypothetical causality between higher education and better health [14]. It is therefore much in line with results from earlier economic studies [16, 21, 46, 47]. The study of Häkkinen et al. [26] also identifies a significantly positive connection between education and general health, but it stresses the allocative efficiency of education via lifestyle choices, as opposed to the productive efficiency of education; both findings are exclusively for males. In our study, education seems to play an important role in reducing caries via its dominant direct effect rather than its indirect effect through dental care use (cf. [46, 48]). Based on the computed elasticities of education, among males an increase of *one* year of schooling directly reduces caries by 4.9% and ultimately alleviates caries by 4.6%. This suggests that policy alternatives aimed at increasing males' general education seem to directly reduce caries. However, the marginal benefit of education on caries among the males is relatively small compared to, for example, that of a healthy diet (Table 3). Hence, preventive efforts to promote dental health should instead be focused on healthy nutrition and dietary habits.

We find no significant direct association of education with caries among females or that of education with dental care use between genders. The latter non-association may be attributed to the overall high level of educational attainment among young adults, while the impacts of education on dental health are probably dampened by the notably high educational status when compared internationally among females in Finland [49]. Education was also not found to be significantly related to dental care utilization among young adults [50]. Perhaps, these individuals have kept on the habits of using dental care in later periods regardless of formal education because they used to use regular pre-school and school dental care earlier.

Caries among females is found to be negatively dependent upon their adolescent school achievement and childhood general health as measured by birth weight. The former negative effect still exists even when the genetic factor is removed from the caries equation. This suggests that under the present framework, causality between dental health and education comes about as more educationally successful female adolescents are better able to manage or avoid dental health problems in early adulthood. This supports the hypothetical view that good health is associated with the adolescent cognitive development [28]. It is also possible that adolescent school achievement is correlated with current education and the error term in the caries equation, which then affects caries. To investigate this, excluding all the covariates relating to childhood and youth, we re-estimated the caries equations. The new coefficient estimates of the respective covariates obtained, in absolute values, were generally a little stronger. For males, the metropolitan domicile was not significant at a 5% level (t=1.75) but the rest of the significant variables remained significant. For females, education was then significantly related to caries (t=−2.47). These findings indicate that the inclusion of information on the past has enabled us to detect the effects of the time variant metropolitan residence and adolescent school achievement on current dental health what we may not be able to identify in the case of a mere cross-sectional work. Moreover, based on the finding for females, it may be argued that the effect of education on current dental health is absorbed into the effect of adolescent school achievement. If this achievement variable—a mean score of all school subjects at age 16, reflecting a pupil's intelligence—can be considered as an important determinant of the years of formal schooling that one will ultimately complete beyond approximately age 30, then it may be viewed as the early forerunner of the positive effect of formal schooling on dental good-health for female young adults. In this respect, our finding is quite accordant with the result of Shakotko et al. [28].

Some family background effects are found (mother's schooling, father's socioeconomic status) on the young adults' general health in the study of Häkkinen et al. [26]. Here, no such associations and no significant association of income with caries or that of income with dental care use are found. If parental schooling can be viewed as representing parents' efficiency in the production of their offspring's dental health (caries) and cognitive development (adolescent school achievement), which has a significantly negative association here, one may argue that parental schooling also has an indirect positive effect on dental good-health in early adulthood. Nonetheless, our findings suggest that the Finnish primary oral health care policy seems to have achieved its main objective by eliminating the direct effects of family background and income on the study individuals' oral health and by diminishing the effects of income on their dental care use. However, this does not ensure that socioeconomic equity in both dental health and utilization among those individuals would be achieved when they become middle-aged or even older. Given that caries is affected by sociobehavioral factors, health and dental health education needs to be improved to reduce caries. Otherwise, public subvention for dental care and better availability may increase demand and enhance equity in the use of dental services among different population groups, but they would barely result in comprehensive changes towards healthy habits that can control and prevent caries. Besides, since the current public practice of treatment is based on assessed risks of dental diseases and thus on individual need, the major responsibility for one's own dental care use and dental health rests with each individual. Further, at the end of the 1990s positive development of the DMFT levels among children and adolescents was discontinued and the DMFT levels among children under school age were even widened [10]. Therefore, the role of parents is likely to be more decisive as they have to make more efforts to both support and enhance their children's use of preventive dental care and oral health.

One concern relating to our measure of dental health is that caries was a self-reported disease. This is subject to biases relating to level of information, observation and reporting. According to a clinical dental examination conducted with the Health 2000 health examination survey, among those examined aged 30–34, only 17% of females but 36% of males had decayed teeth [41]. This suggests, when referring to our figures (Table 2), that females may, for example, tend to be more sensitive to detect and report caries than males, which might be a result of their high educational level and thus better knowledge of dental diseases. Hence, among the females in the study the real prevalence of caries was probably lower than that reported and our estimation results concerning both genders would be somewhat evened out. Other possible selection biases in this study could be considered as rather small because information on the past was obtained for the entire cohort and the response rate of the latest follow-up study (75.3%) was high. Second, to the extent that the probability of participating in the sample was greatly positively associated with education, those lower-educated cohort members outside the sample could likely have more unhealthy habits and experience higher levels of caries. In this respect, the real effects of education and health behavior on caries could be higher than our results have indicated. Third, religious and cultural factors in Northern Finland could possibly impinge on the production of dental health via both the role and the effects of the lifestyle choices. Nevertheless, Finnish adolescents' health behavior was found to be affected by socioeconomic background rather than cultural or socioregional factors [51, 52]. Also, geographical mobility of the population has likely mitigated to some extent or mixed the possible impacts of the original cultural context on health behavior.

Among the direct effects of the explanatory variables, the *t*-values of the regular dental attendance variable in the visit equations are highest. While suggesting that dental care utilization is highly dependent on regular dental attendance, this would call for a close look into the connection between the above-mentioned variables. One method proposed to control the effect of regular dental attendance on utilization is an *ad hoc* two-stage residual approach [20, 53]. Alternatively, to model oral health while allowing for both the impact of regular dental attendance on utilization

and the impact of utilization on oral health, a possible extension would be a simultaneous three-equation probit model, but this model still requires further investigation.[5] This trivariate model approach may imply that some of our current results might be somewhat biased downward. However, we can argue that if endogeneity concerning regular dental attendance were also taken into account, the total effects could be much more substantial on the part of some explanatory variables.

Our recursive model, whose specification was in fact driven by the 1997 survey, does not account for the influence of oral health on dental care utilization. In addition, the previous 1980 survey contained no information on utilization and on oral health and no new survey has been conducted since 1998. Therefore, we could not use the longitudinal dimension of the birth cohort data to explore the joint determination of dental health status and the utilization or the dynamic relationship between the dependent variables for a longer period. One advantage of longitudinal data is that we can study oral health and utilization with appropriate information sets. We can use lagged dental health status to predict past utilization, thus removing potential endogeneity associated with using current measures of dental health status. We can also include the lagged dependent utilization variable as a regressor so as to model current utilization and use lagged dental health status to predict current dental health, capturing state dependence. In a related study field, Propper [31] has analyzed the dynamics of private health care utilization in the UK accounting for state dependence using the British Household Panel Survey (BHPS). Nolan [36] has examined the determinants of GP visiting in Ireland, controlling for both state dependence and unobserved individual heterogeneity, making use of panel data from the Living in Ireland Survey. These studies have shown that state dependence is highly significant, implying that there is a strong continuance or persistence in health care use from one period to the next. Having explored the dynamics of self-assessed health in the BHPS, Contoyannis et al. [54] introduce evidence of persistence in health explained by state dependence and individual heterogeneity. All these findings, as regards our study, suggest that caries might tend to be repeated or recurring throughout many periods of an individual's life and regular dental care use would play an important role in reducing caries. However, further evidence on possible persistence in dental ill-health, taking account of habitual utilization needs to be presented by drawing on appropriate longitudinal data that contain not only dental clinical examinations but also utilization.

5 For extensions of the bivariate probit model and a multivariate probit model, for example, see [32], pp. 856–857.

CONCLUSION

To conclude, we found evidence to support a hypothetical causality between dental health and better education among males and between dental health and adolescent school achievement—the early forerunner of the effect of education—among females. To the extent that lifestyle and health behavior still change and become shaped with age and completed education and their effects on oral health will begin to show themselves in later life, attention should be unceasingly paid to healthy practices like visiting the dentist regularly, using dental care and brushing teeth regularly throughout the life cycle. Brushing at least twice a day is a useful and effective means of self-care to prevent caries and preserve teeth. Given that dental caries is a preventable disease, to attain favorable dental health and potential long-term benefits in promoting oral health, appropriate policies and public health measures aimed at improving dental health education and reducing the detrimental effects of common risk factors on dental health should also be strengthened.

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Appendix 1. Original data, sources of attrition and study sample

	Number of cases
Original cohort with all live births	12058 (12231, all births)
First follow-up study in 1980 (at the age of 14)	
Alive cohort members	11780
Returned postal questionnaires	11010
Second follow-up study in 1997 (at the age of 31)	
Alive cohort members	11637
Those to whom the postal questionnaire was sent	11541
Returned postal questionnaires	8767
Eligible replies	8690
Cohort members included in the study data (after deleting those cases with missing data on all independent variables)	5020

Appendix 2. List of variables and variable definitions

Variable	Definition
Dependent variables	
caries	= 1 if a person reported that s/he had dental caries at the time s/he responded to the questionaire
visit	= 1 if the person had at least one visit to a dentist during the year previous to the data collection time. A measure that describes utilization of dental care
Independent variables	
Variables relating to the birth time	
bweight	The person's birth weight (in kilograms)
bmschool	The number of school years of the mother
bmsmoke	= 1 if the person's mother smoked when she expected her/him
brural	= 1 if parents lived in a rural area at the time of their child's birth
Variables relating to the youth time (at the age of 14)	
y14fses1	= 1 if father's socioeconomic class was highest (professionals)
y14fses2	= 1 if father's socioeconomic class was second highest (skilled workers)
y14fses3	= 1 if father's socioeconomic class was lowest or second lowest (farmers or unskilled workers); reference category
y14fsmok	= 1 if father smoked
y14smoke	= 1 if the person smoked
y14alco	= 1 if the person drank alcohol at least once a month
y14sport	The person's total number of sport activities in a month
y14score	The person's average score of all school subjects completed by the end of compulsory school
y14illmi	= 1 if the person had mild illness of long duration during the year s/he was 14 years old
y14illgr	= 1 if the person had severe illness of long duration during the year s/he was 14 years old
Health and dental health behavior at the age of 31	
alco	The total consumption of alcohol per day (in grams)
sport	The total number of minutes spent on heavy exercise in a month (/10)
bm	= the person's body mass index (= kg/m2 where kg is the weight in kilograms and m is the height in meters)
smokedly	= 1 if the person started smoking in the past and currently smokes seven days a week
dietgood	= 1 if the person consideres his/her food consumption during the previous 6 months as healthiest or second healthiest according to a structured 6-point scale of the food frequency questionnaire
sugar	= 1 if the person uses sugar when drinks coffee/tee
softd	= 1 if the person drinks soft drink on average once or more times a day
canchoc	= 1 if the person eats candies and/or chocolate on average once or more times a day
brushing	= 1 if the person brushes her/his teeth at least twice a day
nadult	The total number of adults in the family
nchild	The total number of children in the family
Individual characteristics at the age of 31	
lninc	= Ln (self-reported yearly gross income (in FIM; € 1 = FIM 5.9457) of the family per equivalent adult)
eduyrs	The number of school years completed prior to the 31-year follow-up time
workfull	= 1 if the person works full-time
student#	= 1 if the person is a student
unempl	= 1 if the person is unemployed
occuelse	= 1 if the person has an occupation/profession not mentioned above; reference category
metropol	= 1 the person resides in the metropols of Helsinki, Espoo, Kauniainen and Vantaa

Variable	Definition
areaelse	= 1 if the person resides in an area other than the metropols; reference category
checkreg	= 1 if the person visits a dentist regularly at least once every two years
Dental health stock at the age of 31	
teeth	= 1 if at least one natural tooth is missing
allteeth	= 1 if all natural teeth remain; reference category
malocclu	= 1 if the person reports that s/he had had malocclusion diagnosed by a dentist that required orthodontic treatment
Price of dental care and provider characteristics in the previous year	
visitime	Self-reported total time (in hours) required for a visit to the dentist, including travel, waiting and treatment time
dpratio	The number of dentists working in each health center district per 1000 residents
careall	= 1 if the municipal health center provided dental care for the whole population
Utilization of dental care during the previous year, visit (see above)	

These 31-year-old students did not represent a homogenous group of conventional students. For example, some of them could be studying because of unemployment.

Appendix 3. Tests of the null hypothesis of zero correlation coefficient in the recursive bivariate probit model

Model	Log likelihood	Test statistic		*p*-value	Decision	Choice of model
Caries (Equation 1)	-2898.52	Likelihood ratio	$\chi^2(1) = 2.229$	0.136	Accept null hypothesis that $\rho = 0$	Recursive probit model of two single equations
Visit (Equation 2)	-3096.93	Wald	$\chi^2(1) = 3.364$	0.067		
Both single equations	-5995.45					
Bivariate probit	-5994.34					
correlation $\rho = -0.5066$						
std error = 0.2763						

Appendix 4. Chow-type tests of parameter homogeneity for two subsamples

Model	Log likelihood				Likelihood ratio test		
	Subsample			Whole sample	Likelihood ratio statistic	Degree of freedom	*p*-value
	Females	Males	Total				
Caries (Equation 1)	-1480.61	-1400.72	-2881.33	-2900.00	37.35	34	0.318
Visit (Equation 2)	-1668.18	-1424.69	-3092.87	-3105.46	25.18	12	0.014
Recursive probit model	-3148.79	-2825.41	-5974.20	-6005.46	62.53	46	0.053

Appendix 5. Computing marginal effects and total effects for the recursive probit model of two single equations

Let's denote the probabilities for the positive outcomes of the recursive probit model of two single equations for a representative individual as[#]

(A1) $E(h \mid x, c, z) = \Pr(H = 1 \mid x, c) = \Phi(\beta' x + \gamma c + \delta z)$ [Having caries]

(A2) $E(c \mid g, z) = \Pr(C = 1 \mid g) = \Phi(\alpha' g + v z)$ [Using dental care]

where z denotes a certain, individual exogenous variable, *c* (dental care use) in equation (A1) is a dummy explanatory variable, *x* and *g* are vectors of all other continuous and dummy exogenous variables; β' and α' are vectors of coefficient parameters associated with the vectors *x* and *g* respectively, and γ, δ and v are coefficient parameters.

Let's first assume that z is a continuous variable. The partial derivatives of the probabilities (A1) and (A2) with respect to *z* are $m_{h,z|c=1} = \phi(\beta' x + \gamma + \delta z)\delta$, $m_{h,z|c=0} = \phi(\beta' x + \delta z)\delta$ and $m_{c,z} = \phi(\alpha' g + vz)v$, where $\phi(.)$ is a standard normal density. The unconditional probability of having caries is

(A3) $$E(h \mid x, z) = E\{E(h \mid c, x, z)\} =$$
$$\Phi(\alpha' g + v z)\,\Phi(\beta' x + \gamma + \delta z) + [1 - \Phi(\alpha' g + v z)]\Phi(\beta' x + \delta z).$$

Differentiating (A3) with respect to *z* gives the total effect of *z* on the probability of having caries. With some small change in the terms used, it can be written as

(A4) $$m_{h,z} = \Pr(C = 1 \mid g)\, m_{h,z|c=1} + \Pr(C = 0 \mid g)\, m_{h,z|c=0}$$
$$+ [\Pr(H = 1 \mid x, c = 1) - \Pr(H = 1 \mid x, c = 0)]m_{c,z}$$

where the component in the square brackets of the third term on the right-hand side of (A4) represents the marginal effect of the dummy exogenous variable *c*.

Now assume that *z* is a dummy variable. The total effect of *z* on the probability of having caries is

(A4') $$E(h \mid x, z = 1) - E(h \mid x, z = 0) = \Phi(\alpha' g + v)\,\Phi(\beta' x + \gamma + \delta)$$
$$+ [1 - \Phi(\alpha' g + v)]\,\Phi(\beta' x + \delta) - \Phi(\alpha' g)\,\Phi(\beta' x + \gamma) - [1 - \Phi(\alpha' g)]\,\Phi(\beta' x).$$

[#] Please note that all notations used here only concern the calculation of marginal and total effects of the covariates.

STAKES

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