Eur J Health Econom 2003 · 4:263–270
DOI 10.1007/s10198-003-0197-y
Published online: 26. August 2003

Mikael Bask[1] · Maria Melkersson[2]
[1] Department of Economics, Umeå University, Sweden
[2] SOFI, Stockholm University, Sweden

Should one use smokeless tobacco in smoking cessation programs?

A rational addiction approach

It is well-known that cigarette smoking is harmful to health and leads to substantial costs for society [6]. Therefore, reducing the number of smokers would benefit both individuals and society. However, it is known to be difficult to stop smoking as nicotine is a highly addictive substance, and relapses are common among smokers who try to quit [15]. We examine whether there are any attractive alternatives to cigarettes for a smoker who wants to quit, other than completely abstaining?

One product that differs from pharmaceutical nicotine replacements such as gum and patches is the Swedish moist snuff, locally known as snus. This is an important nicotine source in addition to cigarette smoking in Sweden, and a recent survey found that 15% of men (only) smoke daily, 18% (only) take snus, and 2% are mixed users, while among women the corresponding figures are 22%, 1%, and almost 0% [12]. Sweden is the only country in Europe where the prevalence of smoking is higher among women than among men [7]. Some claim that the most important explanation is the Swedish snus. Snus probably also offers a much better substitute for cigarette smoking than patches and other nicotine replacement therapy medications because the way in which snus delivers nicotine is closer to that with cigarettes. Cigarettes and snus both give the user a "rush" of nicotine which, for example, nicotine gum or patches do not. Further, the social habit of taking snus is probably, at least for men, closer than gum and patches to the social habit of smoking cigarettes. Moist snuff, but not snus, has been used with success in smoking cessation programs, although not in Sweden [16].

All tobacco products are highly addictive, but the negative health effects from taking snus are less than those from smoking [9, 10]; it is also less harmful than the snuff found, for example, in the United States as it has a lower concentration of nitrosamines. Nevertheless snus is known to contain many carcinogenic substances, although it has yet not been proved to produce cancer in humans (on oral cancer see [13]). However, there are risks other than cancer associated with snus taking. The effects of nicotine include increases in heart rate, blood pressure, cardiac output, and coronary blood flow, although no increased risk of cardiac infarction has been found [3, 10].

When modeling the demand for addictive goods, the most widely used framework is the rational addiction model proposed in the seminal paper by Becker and Murphy [1]. In the present study, we extend their rational addiction model to include two addictive goods, cigarettes and snus. (There are many empirical analyses of the demand for two or more addictive goods, but these are not usually based on any specific theoretical framework; for overviews see [4, 6]). The proposed model will enable us to investigate whether the less harmful snus contributes to less or more smoking. In other words, should one encourage the use of snus in smoking cessation programs? With this in view, we apply the rational addiction model to the Swedish tobacco market and estimate demand equations for cigarettes and snus using aggregated annual time series data (in first differences) for the period 1964–1997.

The rest of this contribution is organized as follows: after developing a theoretical framework for the consumption of two addictive goods we present the dataset used together with the empirical results and a discussion of the results.

Rational addiction with two addictive goods

A consumer is said to be addicted to a good, for example, cigarettes, if an increase in past consumption causes present consumption to rise. This behavior is usually assumed to involve reinforcement and tolerance. Reinforcement means that an increase in past cigarette consumption increases the craving for present consumption and has the important implication that the consumption of cigarettes at different periods in time are complements. On the other hand, tolerance means that

This revised version was published online in November 2003 with corrections in many equations.

the satisfaction from a given consumption level is lower when past cigarette consumption is greater. Reinforcement requires that an increase in past cigarette consumption raises the marginal utility of present cigarette consumption. This is also a sufficient condition for addictive behavior if the consumer is myopic. However, a rational consumer also considers the future negative consequences of harmful behavior. Reinforcement requires that past cigarette consumption stimulates present consumption by more than it is reduced through the harm from future consumption.

Assume a representative consumer with the instantaneous utility function:

$$U[t])=U(c[t], s[t], G[t], H[t], y[t]), \quad (1)$$

where c[*t*] and s[*t*] are two addictive goods, cigarettes and snus. Both goods provide the user with nicotine, and in this sense they are substitutes for one another. G[*t*] and H[*t*] are two habit stocks which measure the degree of addiction, and y[*t*] is a composite of non-addictive goods. Since addictive behavior implies linkages in the consumption over time, it is essential to relax the common assumption of time-separable utility. The simplest way to relax this assumption is to allow utility in each period to depend on the amount of consumption in that period and in the previous period [2]. In our case, a simple formulation of the habit stocks is:

$$\begin{cases} G[t] = c[t-1] + \delta s[t-1] \\ H[t] = (1-\delta)s[t-1] \end{cases}, \quad (2)$$

where $0 \leq \delta \leq 1$. Two extremes are obtained by setting δ=0, which is the case of two separate habit stocks, and by setting δ=1, which is the case of a common habit stock. The latter case assumes that cigarettes and snus are perfect substitutes. The justification for two habit stocks is that there are social and psychological habits connected with one particular nicotine source. This source may not be switched without certain adjustment costs [14].

The marginal utility derived from smoking is assumed to be positive since it relaxes the user through the effects of its nicotine content, but at a decreasing rate, i.e., $U_c>0$ and $U_{cc}<0$ [5]. The same holds for snus and the composite good, i.e., $U_s>0$, $U_{ss}<0$, $U_y>0$, and $U_{yy}<0$. Due to tolerance the habit stocks affect utility negatively, and it is also assumed to do this at an increasing rate, i.e., $U_G<0$, $U_H<0$, $U_{GG}<0$, and $U_{HH}<0$. Thus, we follow Chaloupka [5] and assume a direct negative health effect from the habit stocks. Because each good is reinforced separately, $U_{cG}>0$, $U_{sG}>0$, and $U_{sH}>0$. (Note that the level of U_{cH} is independent of past cigarette smoking.) Furthermore, it is reasonable to believe that if greater consumption of snus makes it easier to stay away from smoking or to stop smoking completely, necessary conditions are that $U_{cs}<0$ and $U_{GH}<0$. However, if snus consumption instead reinforces cigarette smoking, we obtain $U_{cs}>0$ and $U_{GH}>0$. Finally, consumption of the composite good is assumed to have no effect on the marginal utility derived from consuming cigarettes and snus, i.e., $U_{cy}=U_{sy}=U_{Gy}=U_{Hy}=0$.

The appropriate budget constraint for the representative consumer is:

$$\sum_{t=1}^{\infty}(1+r)^{-t}(p_c[t]c[t]+p_s[t]s[t]+y[t]) = W, \quad (3)$$

where $r>0$ is the constant interest rate, $p_c[t]$ and $p_s[t]$ are money prices of cigarettes and snus, respectively, and W is the present value of wealth. The money price of the composite good is the numeraire. The representative consumer's problem is to choose $\{c[t]\}_1^\infty$, $\{s[t]\}_1^\infty$ *and* $\{y[t]\}_1^\infty$ to maximize the discounted stream of utilities:

$$\max_{c[t],s[t],y[t]}\sum_{t=1}^{\infty}(1+\sigma)^{-t}U(c[t],s[t],G[t], H[t],y[t]), \quad (4)$$

subject to the budget constraint in Eq. 3, the formulation of the habit stocks in Eq. 2, and given c[0], s[0], and y[0], where σ>0 is the constant rate of time preference. Assuming perfect capital markets, the rate of time preference is equal to the interest rate, i.e., σ=r. Note that this assumption, in combination with perfect foresight (as we have in our model), implies that the representative consumer can freely borrow and lend money, i.e., consume future (known) income today and save current income for the future. That is, a change in the distribution of incomes over time does not influence current consumption (which is easily shown mathematically). As a consequence, we use instead the present value of wealth in our model.

In the literature, a standard technique used to derive demand equations is to approximate the instantaneous utility function in the neighborhood of steady state by a quadratic function in the arguments. If we substitute Eq. 2 and the appropriate quadratic utility function into the maximization problem in Eq. 4, the following demand equations can be derived for cigarettes and snus, respectively (see the Appendix for a derivation of Eq. 5 and Eq. 6, and explicit expressions for the parameters):

$$c[t]=\beta_{10}+(1+r)\beta_{11}c[t-1] +\beta_{11}c[t+1]+\beta_{12}s[t-1]+\beta_{13}s[t] +\beta_{14}s[t+1]+\beta_{15}p_c[t], \quad (5)$$

where $\beta_{10}>0$, $\beta_{11}>0$, $\beta_{12}>0$, $\beta_{13}<0$, $\beta_{14}>0$, and $\beta_{15}<0$, and:

$$s[t]=\beta_{20}+(1+r)\beta_{21}s[t-1] +\beta_{21}s[t+1]+\beta_{22}c[t-1]+\beta_{23}c[t] +\beta_{24}c[t+1]+\beta_{25}p_s[t], \quad (6)$$

where $\beta_{20}>0$, $\beta_{21}>0$, $\beta_{22}>0$, $\beta_{23}<0$, $\beta_{24}>0$, and $\beta_{25}<0$. Note that the parameter for lagged consumption equals the effect of lead consumption of the same good multiplied by 1+r. Testing this restriction has, in the literature, been used as a "test" of the rational addiction hypothesis, i.e., it has been taken as evidence supporting the model given that the implied interest rate is reasonable. If we assume a common habit stock for cigarettes and snus, i.e., δ=1 in Eq. 2, lagged cigarette consumption has the same effect as lagged snus consumption on current consumption, i.e., $(1+r)\beta_{11}=\beta_{12}$ and $(1+r)\beta_{21}=\beta_{22}$. (Set δ=1 in Eq. 15 and Eq. 16 in the Appendix.) Thus we can test the hypothesis of a common habit stock for cigarettes and snus.

The long-run demand elasticities are of interest since these give a measure of the response, between steady-states, to a permanent change in price. As the model consists of two goods, cross-price elasticities are also derived and estimated (see the Appendix for explicit expressions for the elasticities). Depending on the signs of the cross-price elasticities, it is possible to decide whether snus taking contributes to a decrease or an increase in smoking.

However, the consumption of cigarettes and that of snus are clearly two simultaneous decisions. Accordingly, we combine the two demand equations presented above, i.e., Eq. 5 and Eq. 6 and obtain the following "semi-reduced" system (see the Appendix for explicit expressions for the parameters):

$$c[t]=\beta_{30}+\beta_{31}c[t-1]+\beta_{32}c[t+1] +\beta_{33}s[t-1]+\beta_{34}s[t+1]+\beta_{35}p_c[t] +\beta_{36}p_s[t], \quad (7)$$

and:

$$s[t]=\beta_{40}+\beta_{41}s[t-1]+\beta_{42}s[t+1] +\beta_{43}c[t-1]+\beta_{44}c[t+1]+\beta_{45}p_s[t] +\beta_{46}p_c[t]. \quad (8)$$

It is not possible in this case to determine the signs of the parameters. Thus, rational addiction can still be present, even if there are negative effects on the amount of current consumption from both lagged and lead consumption of the same good. However, although it is not possible to investigate whether rational addiction is present, it is still possible to derive and estimate the long-run demand elasticities (see the Appendix for explicit expressions for the elasticities).

Data and empirical results

Our estimations are based on aggregated annual time series data for the period 1964–1997; covering cigarette (millions of cigarettes) and snus (thousands of kilos) consumption and their respective real prices. The latter are the nominal price per packet of cigarettes or per box of snus deflated by a consumer price index. The quantities are transformed into packs of cigarettes (20 cigarettes/pack) and boxes of snus (15 g/box) per capita for those aged 15 years or over. In the estimations, we follow our theoretical model closely and do not include other explanatory variables. **Table 1** presents a zero-order correlation matrix for some of the time series, and **Table 2** presents descriptive statistics for our dataset [sources of the dataset: Statistics Sweden (cigarettes) and Swedish Match (snus); the dataset is available on request].

Most empirical applications of the rational addiction model using time series have used these in levels [4]. However, we know that if the time series are non-stationary, this can produce spurious results [8]. Therefore, we have used an augmented Dickey-Fuller test on all time series following the procedure proposed by Enders [8], where all tests are performed using two lags. Almost all time series have a unit root. However, when the time series were tested in first differences, none of them had a unit root. Therefore, all estimations are made with all variables, including the instruments, in first differences.

Table 3 and 4 present the results for the model in Eq. 5 and Eq. 6. (Note that if the model is correctly specified, we have a non-zero intercept in the estimations; however, in order not to introduce bias in the other parameters in the case of misspecification, we allow for a non-zero intercept.) The parameters are presented in **Table 3**, and the interest rates and long-run demand elasticities in **Table 4**. Our assumption of rational addiction means that past, present, and future consumption are necessarily linked over time.

Thus, when modeling the current demand for a good, both past and future consumption will probably be endogenous. To allow for possible endogeneity, we use GMM estimations based on two different assumptions. When estimating cigarette demand, GMM (a) assumes that lagged and lead cigarette consumption are endogenous, while snus consumption is exogenous in all periods. When estimating snus demand, lagged and lead snus consumption are endogenous, while cigarette consumption is exogenous in all periods. The instruments used are the lagged and lead prices, and the lagged, current and lead taxes of the good for which demand is estimated. GMM (b) assumes that both cigarette and snus consumption are endogenous. The instruments used are the lagged and lead prices of both goods, the lagged, current and lead taxes of both goods, and also the lagged, current and lead income per capita.

The Durbin-Watson statistics are presented in **Table 3**, and we see that these are probably acceptably close to 2 (i.e., no serial correlation) in all cases except in GMM (a) for snus, a model for which the adjusted R^2 is also very low. For both GMM (b) estima-

Abstract

Eur J Health Econom 2003 · 4:263–270
DOI 10.1007/s10198-003-0197-y

Mikael Bask · Maria Melkersson

Should one use smokeless tobacco in smoking cessation programs? A rational addiction approach

Abstract
The rational addiction model is often used for empirical analysis of the demand for addictive goods. We propose an extension of the model to include two goods, cigarettes and Swedish moist snuff, locally known as snus. Demand equations are estimated using aggregated annual time series data (in first differences) for the period 1964–1997. The findings from the dataset used give some support to the rational addiction hypothesis. The cross-price elasticities are negative, which indicates that taking snus contributes to increased smoking. Thus it is not advisable to encourage the use of the less harmful snus in smoking cessation programs.

Keywords
Rational addiction model · Smoking cessation programs · Smokeless tobacco · Swedish moist snuff

Table 1

Correlations from time series, annual data for 1964–1997

	Cigarette quantity	Cigarette price	Snus quantity	Snus price	Trend (year)
Cigarette quantity	1.00	_	_	_	_
Cigarette price	−0.75	1.00	_	_	_
Snus quantity	−0.37	−0.04	1.00	_	_
Snus price	−0.86	0.68	0.67	1.00	_
Trend (year)	−0.35	0.04	0.98	0.70	1.00

Table 2

Descriptive statistics, annual data for 1964–1997. Figures are from Statistics Sweden (cigarettes) and Swedish Match (snus). Prices are given in terms of 1997 Swedish crowns

	Mean	SD	Min.	Year[b]	Max.	Year[b]
Cigarettes, packs/capita	77.03	11.54	41.70	1997	91.64	1976
Snus, boxes/capita	11.15	2.66	7.52	1969	15.70	1996
Cigarette price, crowns/pack	27.60	3.24	22.11	1982	38.20	1997
Snus price, crowns/box	9.42	2.88	7.29	1977	19.46	1997
Relative price[a]	6.65	1.22	4.25	1997	8.49	1979

[a] *For 13 cigarettes in relation to 15 g snus, which are the average consumption levels among daily users [12]*
[b] *Year corresponds to the year the respective min or max value is observed*

Table 3

Estimation results (parameters) when the two demand equations are treated as independent (see Eq. 5 and Eq. 6)

	OLS		GMM (a)		GMM (b)	
Cigarettes	**Par.**	***t***	**Par.**	***t***	**Par.**	***t***
Constant	1.764	1.866	1.795	1.749	2.889	7.472
$\Delta c[t-1]$	−0.077	−0.605	−0.068	−0.618	−0.061	−1.102
$\Delta c[t+1]$	−0.380	−3.178	−0.521	−6.123	−0.195	−3.310
$\Delta s[t-1]$	−3.061	−1.117	−3.706	−2.335	−4.935	−3.041
$\Delta s[t]$	−6.514	−1.982	−7.095	−3.812	−4.876	−2.761
$\Delta s[t+1]$	0.715	0.335	1.883	1.477	−1.856	−2.407
$\Delta p_c[t]$	−2.924	−5.424	−2.798	−5.447	−3.556	−16.311
Adj.R^2	0.601	–	0.574	–	0.497	–
DW	1.467	–	1.282	–	1.882	–
Snus	**Par.**	***t***	**Par.**	***t***	**Par.**	***t***
Constant	0.133	2.338	0.284	3.625	0.114	3.711
$\Delta s[t-1]$	0.456	3.122	0.249	1.293	0.321	5.081
$\Delta s[t+1]$	0.189	1.555	−0.220	−2.359	0.318	4.246
$\Delta c[t-1]$	−0.015	−1.910	−0.016	−1.649	−0.014	−2.871
$\Delta c[t]$	−0.017	−1.580	−0.023	−1.895	−0.010	−3.015
$\Delta c[t+1]$	−0.015	−1.946	−0.011	−1.697	−0.012	−5.465
$\Delta p_s[t]$	−0.212	−2.583	−0.179	−3.406	−0.182	−6.441
Adj.R^2	0.448	–	0.050	–	0.377	–
DW	2.114	–	0.967	–	0.956	–

tions, the residuals show no significant correlations at any conventional risk level. We focus mainly on these estimations.

We see in **Table 3** that some of the results are quite unstable across estimation methods. Indeed, we have very short time series since we have access only to annual data. However, one result which is very stable across estimation methods and sets of instruments is that consumption of both cigarettes and snus are negatively and significantly related to their prices. The dataset used gives some support to the rational addiction hypothesis, i.e., that there is a positive effect on the level of current consumption from both the lagged and lead consumption of the same good. In most cases, however, the current demand is significantly but negatively affected by future consumption.

We also want to test the common habit stock hypothesis discussed above. If cigarettes and snus accumulate a common habit stock, lagged cigarette consumption has the same effect as lagged snus consumption on current consumption. In most cases the parameters in question have different signs, and at least one of them is significantly different from zero. This indicates that cigarette and snus consumption do not accumulate a common habit stock, but rather two habit stocks.

Turning to the "semireduced" system, the more relevant case, we first estimate Eq. 7 and Eq. 8 as a seemingly unrelated system (SUR). This is the equivalent of ordinary least squares (OLS) but allows for heteroskedasticity and contemporaneous error correlations in the system. We then carry out a GMM estimation in which both past and future consumption are allowed to be endogenous. We use the lagged and lead prices of the goods, and the lagged, current and lead taxes as instruments.

Table 5 presents the results. Note, again, that the consumption of both cigarettes and snus is negatively and significantly related to the price of the respective good. Moreover, both past and future snus consumption has a positive and significant effect on the current demand for snus. Recall, however, that it is not possible to test the rational addiction hypothesis since it is not possible, from theory, to determine the signs of the parameters. Looking at the long-run demand elasticities,

Table 4

Estimation results (interest rates and long-run elasticities) when the two demand equations are treated as independent: The interest rate can be estimated in two different ways; however, the interest rate is given only when rational addiction is present. The *p* value refers to an *F* test of the null hypothesis of an interest rate equal to 5%

	OLS	GMM (a)	GMM (b)
Interest rate (Eq. 5)	–	–	–
p-value	–	–	–
Interest rate (Eq. 6)	141.3%	–	0.9%
p-value	0.471	–	0.899
Elasticities			
$\partial c/\partial p_c \times p_c/c$	−3.69	−0.89	−13.77
$\partial s/\partial p_s \times p_s/s$	−2.59	−0.22	−5.78
$\partial c/\partial p_s \times p_s/c$	2.28	0.18	7.77
$\partial s/\partial p_c \times p_c/s$	3.37	0.32	9.49

Table 5

Estimation results (parameters and long-run elasticities) when the two demand equations are treated as simultaneous (see Eq. 7 and Eq. 8)

	SUR		GMM	
Cigarettes	**Par.**	***t***	**Par.**	***t***
Constant	1.414	1.722	2.469	4.256
Δc[t-1]	−0.161	−1.255	0.180	2.238
Δc[t+1]	−0.321	−3.075	−0.304	−5.441
Δs[t-1]	−4.690	−2.117	−9.090	−6.906
Δs[t+1]	−1.151	−0.632	−3.060	−4.172
$\Delta p_c[t]$	−1.561	−2.274	−2.822	−6.782
$\Delta p_s[t]$	−2.512	−1.771	−0.202	−0.301
$Adj.R^2$	0.579	–	0.392	–
DW	1.944	–	2.308	–
Snus	**Par.**	***t***	**Par.**	***t***
Constant	0.103	2.077	0.094	2.374
Δs[t-1]	0.470	3.526	0.600	4.466
Δs[t+1]	0.222	2.028	0.199	2.567
Δc[t-1]	−0.005	−0.597	−0.021	−5.098
Δc[t+1]	−0.010	−1.524	−0.010	−2.242
$\Delta p_s[t]$	−0.047	−0.557	−0.154	−3.053
$\Delta p_c[t]$	−0.050	−1.202	0.008	0.325
$Adj.R^2$	0.418	–	0.229	–
DW	2.219	–	2.408	–
Elasticities				
$\partial c/\partial p_c \times p_c/c$	−0.18	–	1.58	–
$\partial s/\partial p_s \times p_s/s$	−0.07	–	0.94	–
$\partial c/\partial p_s \times p_s/c$	−0.17	–	−1.49	–
$\partial s/\partial p_c \times p_c/s$	−0.34	–	−1.58	–

and focusing on GMM as probably the most relevant case, the elasticities of cigarette and snus demand are positive. The cross-price elasticities are negative, which indicates that snus taking contributes to increased smoking. Thus, even if snus taking is less harmful than cigarette smoking, it is not advisable to encourage its use in smoking cessation programs.

Concluding remarks

In summary, we have developed a theoretical framework for rational addiction with two addictive goods, cigarettes and snus. The proposed framework can of course be applied to other pairs of goods, and the generalization to more than two goods is straightforward. According to the estimation results, the dataset used did give some but not full support to the rational addiction hypothesis. However, one should not be too hasty and reject the hypothesis that consumers behave rationally when consuming addictive goods. There are two reasons for exercising caution.

Firstly, our model is based on the utility maximization of a representative consumer. This may not be appropriate if we actually have heterogeneous agents. Consumption of, for example, cigarettes at one particular point in time is the result of a complex flow of actions on the part of individuals who start smoking, quit smoking, and alter their consumption levels. To capture these different decisions might require data on a less aggregated level than those we have used. (For data on the individual or cohort level, see, e.g., Jiménez-Martín et al. [11]). Secondly, our estimations have been kept very close to the theoretical framework. For instance, we have abstained from adding exogenous variables not included in the model, like substitutes and complements to cigarettes and snus, such as alcohol.

Finally, should one encourage the use of snus in smoking cessation programs? The cross-price elasticities are all negative when we treated the decisions to consume cigarettes and snus as simultaneous. This means that it is not advisable to encourage the use of snus in smoking cessation programs, even if snus taking is less harmful than cigarette smoking.

Corresponding author

Mikael Bask

Department of Economics, Umeå University,
90187 Umeå, Sweden
e-mail: mikael.bask@econ.umu.se

Acknowledgements

Valuable comments and suggestions from participants at seminars at Umeå University, Stockholm University (SOFI), and Luleå University of Technology are gratefully acknowledged. We are grateful to Sam Cameron for providing us with helpful comments and suggestions. Finally, we thank Suzanne Grahn at Swedish Match for providing the time series of snus prices. The usual disclaimer applies.

Appendix

Derivation of Eq. 5 and Eq. 6

The instantaneous utility function can be approximated by:

$$\begin{aligned} U(\bullet) \;=\;& \alpha_1 c[t]+\alpha_2 s[t]+\alpha_3 G[t]+\alpha_4 H[t]+\alpha_5 y[t]+\\ & \tfrac{1}{2}u_{cc}c^2[t]+\tfrac{1}{2}u_{ss}s^2[t]+\tfrac{1}{2}u_{GG}G^2[t]+\tfrac{1}{2}u_{HH}H^2[t]+\tfrac{1}{2}u_{yy}y^2[t]+\\ & u_{cs}c[t]s[t]+u_{cG}c[t]G[t]+u_{cH}c[t]H[t]+u_{sG}s[t]G[t]+u_{sH}s[t]H[t]+u_{GH}G[t]H[t], \end{aligned} \tag{9}$$

where the α_i values are positive parameters, and the u_{ij} values are parameters with the same sign as their respective derivatives, for example, $u_{cc}<0$ since $U_{cc}<0$. The maximization problem can be transformed to be a function of cigarettes and snus only:

$$V^*(\bullet)=\gamma W-\frac{(\gamma-\alpha_5)^2}{2ru_{yy}}+\max_{c[t],s[t]}\sum_{t=1}^{\infty}(1+r)^{-t}F(c[t],s[t],G[t],H[t]), \tag{10}$$

given c[0] and s[0], where:

$$\begin{aligned} F(\bullet) \;=\;& \alpha_1 c[t]+\alpha_2 s[t]+\alpha_3(c[t-1]+\delta s[t-1])+\alpha_4(1-\delta)s[t-1]+\\ & \tfrac{1}{2}u_{cc}c^2[t]+\tfrac{1}{2}u_{ss}s^2[t]+\tfrac{1}{2}u_{GG}(c[t-1]+\delta s[t-1])^2+\tfrac{1}{2}u_{HH}(1-\delta)^2 s^2[t-1]+\\ & u_{cs}c[t]s[t]+u_{cG}c[t](c[t-1]+\delta s[t-1])+u_{cH}c[t](1-\delta)s[t-1]+\\ & u_{sG}s[t](c[t-1]+\delta s[t-1])+u_{sH}s[t](1-\delta)s[t-1]+\\ & u_{GH}(c[t-1]+\delta s[t-1])(1-\delta)s[t-1]-\gamma(p_c[t]c[t]+p_s[t]s[t]). \end{aligned} \tag{11}$$

The first-order condition with respect to c[t] is:

$$\frac{\partial V^*(\bullet)}{\partial c[t]}=\frac{\partial F(c[t],s[t],G[t],H[t])}{\partial c[t]}+\frac{1}{1+r}\frac{\partial F(c[t+1],s[t+1],G[t+1],H[t+1])}{\partial c[t]}=0, \tag{12}$$

where:

$$\frac{\partial F(c[t],s[t],G[t],H[t])}{\partial c[t]}=\alpha_1+u_{cc}c[t]+u_{cs}s[t]+u_{cG}(c[t-1]+\delta s[t-1])+u_{cH}(1-\delta)s[t-1]-\gamma p_c[t], \tag{13}$$

and:

$$\frac{\partial F(c[t],s[t],G[t],H[t])}{\partial c[t]}=\alpha_1+u_{cc}c[t]+u_{cs}s[t]+u_{cG}(c[t-1]+\delta s[t-1])+u_{cH}(1-\delta)s[t-1]-\gamma p_c[t], \tag{14}$$

Solve these equations for c[t]:

$$c[t]=\beta_{10}+(1+r)\beta_{11}c[t-1]+\beta_{11}c[t+1]+\beta_{12}s[t-1]+\beta_{12}s[t]+\beta_{14}s[t+1]+\beta_{15}p_c[t],$$

where:

$$\begin{cases} \beta_{10}=-\frac{(1+r)\alpha_1+\alpha_3}{(1+r)u_{cc}+u_{GG}}>0, & \beta_{11}=-\frac{u_{cG}}{(1+r)u_{cc}+u_{GG}}>0,\\ \beta_{12}=-\frac{(1+r)(\delta u_{cG}+(1-\delta)u_{cH})}{(1+r)u_{cc}+u_{GG}}>0, & \beta_{13}=-\frac{(1+r)u_{cs}+\delta u_{GG}+(1-\delta)u_{GH}}{(1+r)u_{cc}+u_{GG}}<0,\\ \beta_{14}=-\frac{u_{sG}}{(1+r)u_{cc}+u_{GG}}>0, & \beta_{15}=\frac{(1+r)\gamma}{(1+r)U_{cc}+U_{GG}}<0. \end{cases} \tag{15}$$

Finally, derive the first order condition with respect to s[t], i.e.: $\frac{\partial V^*(\cdot)}{\partial s[t]}=0$, and solve for s[$t$]:

$$s[t]=\beta_{20}+(1+r)\beta_{21}s[t-1]+\beta_{21}s[t+1]+\beta_{22}c[t-1]+\beta_{23}c[t]+\beta_{24}c[t+1]+\beta_{25}p_s[t],$$

where:

$$\begin{cases} \beta_{20} = -\frac{(1+r)\alpha_2+\delta\alpha_3+(1-\delta)\alpha_4}{(1+r)u_{ss}+\delta^2 u_{GG}+(1-\delta)^2 u_{HH}+2\delta(1-\delta)u_{GH}} > 0 \\ \beta_{21} = -\frac{\delta u_{sG}+(1-\delta)u_{sH}}{(1+r)u_{ss}+\delta^2 u_{GG}+(1-\delta)^2 u_{HH}+2\delta(1-\delta)u_{GH}} > 0 \\ \beta_{22} = -\frac{(1+r)u_{sG}}{(1+r)u_{ss}+\delta^2 u_{GG}+(1-\delta)^2 u_{HH}+2\delta(1-\delta)u_{GH}} > 0 \\ \beta_{23} = -\frac{(1+r)u_{cs}+\delta u_{GG}+(1-\delta)u_{GH}}{(1+r)u_{ss}+\delta^2 u_{GG}+(1-\delta)^2 u_{HH}+2\delta(1-\delta)u_{GH}} < 0 \\ \beta_{24} = -\frac{\delta u_{cG}+(1-\delta)u_{cH}}{(1+r)u_{ss}+\delta^2 u_{GG}+(1-\delta)^2 u_{HH}+2\delta(1-\delta)u_{GH}} > 0 \\ \beta_{25} = \frac{(1+r)\gamma}{(1+r)u_{ss}+\delta^2 u_{GG}+(1-\delta)^2 u_{HH}+2\delta(1-\delta)u_{GH}} < 0 \end{cases} . \tag{16}$$

Parameters in Eq. 7 and Eq. 8

The parameters are:

$$\begin{cases} \beta_{30} = \frac{\beta_{10}+\beta_{13}\beta_{20}}{1-\beta_{13}\beta_{23}}, & \beta_{31} = \frac{(1+r)\beta_{11}+\beta_{13}\beta_{22}}{1-\beta_{13}\beta_{23}}, \quad \beta_{32} = \frac{\beta_{11}+\beta_{13}\beta_{24}}{1-\beta_{13}\beta_{23}} \quad \beta_{33} = \frac{\beta_{12}+(1+r)\beta_{13}\beta_{21}}{1-\beta_{13}\beta_{23}} \\ \beta_{34} = \frac{\beta_{13}\beta_{21}+\beta_{14}}{1-\beta_{13}\beta_{23}}, & \beta_{35} = \frac{\beta_{15}}{1-\beta_{13}\beta_{23}}, \quad \beta_{36} = \frac{\beta_{13}\beta_{25}}{1-\beta_{13}\beta_{23}}, \end{cases} \tag{17}$$

and:

$$\begin{cases} \beta_{40} = \frac{\beta_{10}\beta_{23}+\beta_{20}}{1-\beta_{13}\beta_{23}}, & \beta_{41} = \frac{\beta_{12}\beta_{23}+(1+r)\beta_{21}}{1-\beta_{13}\beta_{23}}, \quad \beta_{42} = \frac{\beta_{14}\beta_{23}+\beta_{21}}{1-\beta_{13}\beta_{23}}, \quad \beta_{43} = \frac{(1+r)\beta_{11}\beta_{23}+\beta_{22}}{1-\beta_{13}\beta_{23}}, \\ \beta_{44} = \frac{\beta_{11}\beta_{23}+\beta_{24}}{1-\beta_{13}\beta_{23}}, & \beta_{45} = \frac{\beta_{25}}{1-\beta_{13}\beta_{23}}, \quad \beta_{46} = \frac{\beta_{15}\beta_{23}}{1-\beta_{13}\beta_{23}}. \end{cases} \tag{18}$$

Long-run demand elasticities

All the price and quantity variables presented below, for example, p_c and c, are prices and quantities in steady state. In the estimations of the long-run demand elasticities, we assume that these steady-state values equalize the mean values in the dataset. The long-run demand elasticities are:

$$\begin{cases} \frac{\partial c}{\partial p_c}\frac{p_c}{c} = \frac{\beta_{15}\left(1-\beta_{21}-\beta_{21}^*\right)}{\left(1-\beta_{11}-\beta_{11}^*\right)\left(1-\beta_{21}-\beta_{21}^*\right)-(\beta_{12}+\beta_{13}+\beta_{14})(\beta_{22}+\beta_{23}+\beta_{24})}\frac{p_c}{c} \\ \frac{\partial s}{\partial p_s}\frac{p_s}{s} = \frac{\left(1-\beta_{11}-\beta_{11}^*\right)\beta_{25}}{\left(1-\beta_{11}-\beta_{11}^*\right)\left(1-\beta_{21}-\beta_{21}^*\right)-(\beta_{12}+\beta_{13}+\beta_{14})(\beta_{22}+\beta_{23}+\beta_{24})}\frac{p_s}{s} \\ \frac{\partial c}{\partial p_s}\frac{p_s}{c} = \frac{(\beta_{12}+\beta_{13}+\beta_{14})\beta_{25}}{\left(1-\beta_{11}-\beta_{11}^*\right)\left(1-\beta_{21}-\beta_{21}^*\right)-(\beta_{12}+\beta_{13}+\beta_{14})(\beta_{22}+\beta_{23}+\beta_{24})}\frac{p_s}{c} \\ \frac{\partial s}{\partial p_c}\frac{p_c}{s} = \frac{\beta_{15}(\beta_{22}+\beta_{23}+\beta_{24})}{\left(1-\beta_{11}-\beta_{11}^*\right)\left(1-\beta_{21}-\beta_{21}^*\right)-(\beta_{12}+\beta_{13}+\beta_{14})(\beta_{22}+\beta_{23}+\beta_{24})}\frac{p_c}{s} \end{cases} , \tag{19}$$

where: β^*_{11}=(1+r)β_{11} and β^*_{21}=(1+r)β_{21}, i.e., we relax the parameter restriction in the model. The long-run demand elasticities, based on the "semireduced" system, are:

$$\begin{cases} \frac{\partial c}{\partial p_c}\frac{p_c}{c} = \frac{(\beta_{33}+\beta_{34})\beta_{46}+\beta_{35}(1-\beta_{41}-\beta_{42})}{(1-\beta_{31}-\beta_{32})(1-\beta_{41}-\beta_{42})-(\beta_{33}+\beta_{34})(\beta_{43}+\beta_{44})}\frac{p_c}{c} \\ \frac{\partial s}{\partial p_s}\frac{p_s}{s} = \frac{(1-\beta_{31}-\beta_{32})\beta_{45}+\beta_{36}(\beta_{43}+\beta_{44})}{(1-\beta_{31}-\beta_{32})(1-\beta_{41}-\beta_{42})-(\beta_{33}+\beta_{34})(\beta_{43}+\beta_{44})}\frac{p_s}{s} \\ \frac{\partial c}{\partial p_s}\frac{p_s}{c} = \frac{(\beta_{33}+\beta_{34})\beta_{45}+\beta_{36}(1-\beta_{41}-\beta_{42})}{(1-\beta_{31}-\beta_{32})(1-\beta_{41}-\beta_{42})-(\beta_{33}+\beta_{34})(\beta_{43}+\beta_{44})}\frac{p_s}{c} \\ \frac{\partial s}{\partial p_c}\frac{p_c}{s} = \frac{(1-\beta_{31}-\beta_{32})\beta_{46}+\beta_{35}(\beta_{43}+\beta_{44})}{(1-\beta_{31}-\beta_{32})(1-\beta_{41}-\beta_{42})-(\beta_{33}+\beta_{34})(\beta_{43}+\beta_{44})}\frac{p_c}{s} \end{cases} . \tag{20}$$

References

1. Becker GS, Murphy KM (1988) A theory of rational addiction. J Polit Econ 96:675–700
2. Becker GS, Grossman M, Murphy KM (1994) An empirical analysis of cigarette addiction. Am Econ Rev 84:396–418
3. Bolinder GM, Ahlborg BO, Lindell JH (1992) Use of smokeless tobacco: blood pressure elevation and other health hazards found in a large-scale population survey. J Intern Med 232:327–334
4. Cameron S (1998) Estimation of the demand for cigarettes: a review of the literature. Econ Issues 3:51–71
5. Chaloupka FJ (1991) Rational addictive behavior and cigarette smoking. J Polit Econ 99:722–742
6. Chaloupka FJ, Warner KE (2000) The economics of smoking. In: Culyer AJ, Newhouse JP (eds) Handbook of health economics, chap 29. North Holland: Amsterdam
7. Dahlgren G (1997) Determinants of the burden of disease in the European Union. Report no F24. National Institute of Public Health: Stockholm
8. Enders W (1995) Applied econometric time series. Wiley: New York
9. Fagerström KO, Ramström L (1998) Can smokeless tobacco rid us of tobacco smoke? Am J Med 104:501–503
10. Huhtasaari F, Asplund K, Lundberg V, Stegamayr B, Wester PO (1992) Tobacco and myocardial infarction: is snuff less dangerous than cigarettes? BMJ 305:1252–1256
11. Jiménez-Martín S, Labeaga JM, López A (1998) Participation, heterogeneity and dynamics in tobacco consumption: evidence from cohort data. Health Econ 7:401–414
12. Melkersson M (2002) Smoking habits and quitting costs in the presence of a close substitute. SOFI, Stockholm University: Stockholm
13. Schildt E-B, Eriksson M, Hardell L, Magnuson A (1998) Oral snuff, smoking habits and alcohol consumption in relation to oral cancer in a Swedish case-control study. Int J Cancer 77:341–346
14. Suranovic SM, Goldfarb RS, Leonard TC (1999) An economic theory of cigarette addiction. J Health Econ 18:1–29
15. Tauras JA (1999) The transition to smoking cessation: evidence from multiple failure duration analysis. NBER working paper no 7412
16. Tilashalski K, Rodu B, Cole P (1998) A pilot study of smokeless tobacco in smoking cessation. Am J Med 104:456–459