Rational Addictive Behavior and Cigarette Smoking

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Cigarette demand equations accounting for tolerance, reinforcement, and withdrawal are derived using the Becker-Murphy model of rational addiction and are estimated using data from the second National Health and Nutrition Examination Survey. Estimates imply that smoking is addictive, individuals are not myopic, and price increases would reduce demand. Implications concerning time preference and addiction are tested by estimating the demand separately for samples based on age and education. Less educated (younger) individuals are found to behave more myopically than more educated (older) individuals, whereas more addicted (myopic) individuals are found to respond more to price, in the long run, than less addicted (myopic) individuals.

I. Introduction

Until recently, economists treated addictive consumption no differently from other consumption, although other social and physical scientists long recognized that addictive goods possess several distinguishing characteristics. These aspects of consumption were ignored, in part, because addiction was considered an irrational behavior not conducive to standard economic analysis (Elster 1979; Winston 1980; Schelling 1984). Thus many think that addictive consumption does not follow the basic law of economics, that of an inverse relationship

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between the "full price" of a good and its consumption, where price includes not only the monetary price but also the negative health effects and legal sanctions associated with consumption. This implies that policies such as stronger enforcement of drug laws, higher fines and longer imprisonment for drug use, higher taxes on alcohol and cigarettes, and the dissemination of information concerning the negative health effects of drugs, alcohol, and tobacco will have little, if any, effect on consumption.

Recent models treat addictive consumption as a "rational" behavior.[1] These models distinguish addictive consumption from other consumption by recognizing that, for addictive goods, current consumption depends on past consumption, incorporating the notions of tolerance, reinforcement, and withdrawal (Donegan et al. 1983; Peele 1985). Tolerance suggests that a given level of consumption yields less satisfaction as cumulative past consumption is higher. Reinforcement implies a learned response to past consumption (i.e., smoking to relieve tension). Finally, withdrawal refers to a negative physical reaction and other reductions in utility associated with the cessation or interruption of consumption.

This paper uses Becker and Murphy's (1988) model of rational addiction to derive and estimate cigarette demand equations that explicitly account for the addictive nature of cigarette smoking.

Cigarette smoking is ideal for empirically testing the rational addiction model. Cigarettes, because of nicotine, are addictive, with smoking the most widespread addictive behavior in today's society. The surgeon general (U.S. Department of Health and Human Services 1989) describes the processes leading to tobacco addiction as similar to those determining addictions to heroin and cocaine. Owing to the high incidence of cigarette smoking and its legality, self-reported measures of smoking should be much more reliable than measures of heroin or other drug use. Similarly, illegal drug price data are likely to be inaccurate, whereas cigarette price and tax data are well reported.

The surgeon general calls cigarette smoking the largest single preventable cause of premature death and disability in the United States,

[1] Rationality in this context implies that the future consequences of current and past behavior are considered in the lifetime utility maximization process and that preferences are stable over time. This does not preclude the application of a relatively high discount rate to the future consequences of the addiction. Some noneconomists and economists alike will be uncomfortable with the use of the term "rational" to describe potentially self-destructive activities (as an anonymous referee notes, to many, the term "rational addiction" sounds like an oxymoron). However, as Stigler and Becker (1977, p. 90) urge, traditional economic analysis should not be abandoned when dealing with complicated behaviors (such as addictions) in the hope that "further explanation will perhaps someday be produced by one of our sister behavioral sciences."

responsible for over 390,000 premature deaths annually (Health and Human Services 1989). Additionally, nonsmokers face a greater risk of cancer from involuntary smoking than from all other air pollutants (Health and Human Services 1986). Thus understanding the effects of efforts to reduce cigarette smoking is of considerable importance.

Since the first surgeon general's report on the health consequences of smoking, the federal government and various state and local governments have tried to discourage cigarette smoking. One policy virtually ignored by the federal government and most state and local governments is the increased taxation of cigarettes.[2]

This paper is the first to empirically test the predictions of the Becker-Murphy model using micro data. As such, it contains the first estimates of the price elasticity of demand for cigarettes based on individual data and offers an interesting comparison to the estimates obtained from state aggregates by Becker, Grossman, and Murphy (1990). Additionally, the use of micro data allows for the testing of some of the predictions of the Becker-Murphy model regarding the relationship between time preference and addiction.

Theoretical Model

Recent economic models of addiction fall into distinct classes on the basis of their approaches to two factors.[3] The first comes from the

[2] Warner (1981) attributes the numerous state excise tax increases of the late 1960s to states' attempts to discourage smoking. These increases led to large differences in prices across states, inducing casual and organized smuggling of cigarettes and discouraging states from using excise taxes to reduce smoking. The federal tax was constant from 1951 until 1983, when it was doubled as part of a deficit reduction act.

[3] Some economic models of addiction describe individuals as having stable but inconsistent short- and long-run preferences. Strotz (1956), e.g., describes the problem as one in which an individual chooses a future consumption path, subject to a budget constraint, so as to maximize utility, but on later consideration changes this plan "even though his original expectations of future desires and means of consumption are verified" (p. 165). He goes on to state that this may lead "rational" consumers (those who recognize the time inconsistency) to precommit their future behavior or to modify their consumption plans so that they will be consistent with future preferences. This seems to be the same type of behavior described by Schelling (1978, p. 290) when discussing smokers: "Everybody behaves like two people, one who wants clean lungs and long life and another who adores tobacco." Thus the nonaddictive (farsighted) personality may enroll in a stop smoking program. Similarly, Thaler and Shefrin (1981, p. 392) describe an individual who is both "a far-sighted planner and a myopic doer" who are continually in conflict. Other discussions of this type of inconsistency can be found in Elster (1979) and Winston (1980). Myopic models of addictions focus on the short-run behavior. For example, Pollak (1968) challenges Strotz, stating that individuals will behave "naively" or myopically, believing that the plan they commit to in each period will be maintained in all future periods, but then will reconsider their plan in each future period. By contrast, the Becker-Murphy and other models of rational addictive behavior treat short-run and long-run activities as part of a consistent utility maximization plan.

treatment of tastes as either endogenous or constant over the life cycle. Endogenous tastes models incorporate addiction by making present tastes dependent on past consumption (Gorman 1967; Pollak 1970, 1976; El-Safty 1976; Hammond 1976). Alternatively, constant taste models, using the household production framework, model addiction by letting the ability to produce the addictive commodity (using the addictive good) depend on past consumption.[4]

The second distinction concerns the addict's rationality. Some treat the addict as behaving myopically, implying that all future effects of the addiction are ignored (Houthakker and Taylor 1970; Spinnewyn 1981; Mullahy 1985). That is, the addict accounts for the dependence of current addictive consumption on past consumption but ignores the dependence of future consumption on current and past consumption when making current decisions. Others treat the addict as rational (Stigler and Becker 1977; Iannaccone 1984; Becker and Murphy 1988). In these models, the addict is assumed to be aware of and to account for the interdependence of past, current, and future consumption when making current consumption decisions.

The first of these distinctions has been called "purely semantic" (Phlips 1983) since the mathematics are the same. Similarly, some myopic models of addiction and their farsighted counterparts are "observationally equivalent," implying that the demand equations resulting from the repeated constrained maximization of an instantaneous utility function are simple transformations of those resulting from the constrained maximization of utility over the life cycle (Phlips and Spinnewyn 1982). Thus assuming rationality leads only to unnecessary complications. This equivalence does not hold in the Becker-Murphy model. As described below, the demand equations derived under the assumption of myopic behavior are substantively different from those developed under the assumption of rational or farsighted behavior.

In the Becker-Murphy model, tastes are constant and the individual is assumed to be rational. While assuming rationality appears strong, it seems more consistent than the assumption of myopic models, in which individuals are aware of the dependence of current consumption on past consumption but ignore the resulting depen-

[4] This paradigm was first used by Stigler and Becker (1977) and is the basis of the work by Iannaccone (1986), Léonard (1986), Becker and Murphy (1988), and Michaels (1988). Barthold and Hochman (1988) present an interesting modification in which preferences are stable, but, for at least some individuals, there are concavities in the implied indifference curves relating the addictive (compulsive) good and a composite good. The resulting demand curve for the addictive good is perfectly inelastic or discontinuous in the concave range, implying, for some, "extreme-seeking" behavior.

dence of future consumption on current and past consumption when making decisions.[5]

At any moment in time, the individual's utility is assumed to be a function of health, $H(t)$, the relaxation produced by addictive consumption, $R(t)$, and a composite of other consumption commodities, $\mathbf{Z}(t)$:

$$U(t) = u[H(t), R(t), \mathbf{Z}(t)], \tag{1}$$

where u is assumed to be concave and to have negative second derivatives for each of the arguments.

Health is assumed to be a function of market goods, such as medical care, and the individual's own time, spent, for example, on exercise (the vector $\mathbf{M}(t)$). These inputs have positive but diminishing effects on health. Health is also affected by cumulative past cigarette consumption or the "addictive stock," $A(t)$. The greater the addictive stock, the lower the level of health, all else constant:

$$H(t) = H[\mathbf{M}(t), A(t)], \quad H_{\mathbf{M}} > 0, H_{\mathbf{MM}} < 0, H_A < 0, H_{AA} < 0. \tag{2}$$

"Relaxation" (the psychological and physiological benefits of smoking) is produced by the addictive good, cigarettes, $C(t)$, and the addictive stock.[6] Increased cigarette consumption has a positive effect on the production of relaxation, whereas greater past consumption has a negative effect. This assumption incorporates the notion of tolerance into the model. To capture reinforcement effects in consumption, the marginal productivity of cigarette consumption in the production of relaxation is assumed larger the larger the level of the addictive stock:

$$R(t) = R[C(t), A(t)], \quad R_C > 0, R_{CC} < 0, R_A < 0, R_{AA} < 0, R_{CA} > 0. \tag{3}$$

The composite good is produced using inputs $\mathbf{X}(t)$, which include market goods and the individual's own time, each assumed to have positive but diminishing marginal productivity:

$$\mathbf{Z}(t) = \mathbf{Z}[\mathbf{X}(t)], \quad \mathbf{Z}_{\mathbf{X}} > 0, \mathbf{Z}_{\mathbf{XX}} < 0. \tag{4}$$

[5] As Becker and Murphy note, the large reductions in cigarette smoking resulting from the spread of evidence on its health consequences beginning in the late 1950s clearly indicate that most smokers were not behaving myopically. If they were myopic, then the new evidence on the future consequences of their addiction would not have had any effect on their smoking patterns.

[6] Ashton and Stepney (1982) include in the short-term psychological and physiological effects of smoking the maintenance of performance levels in the face of fatigue and the attenuation of the effects of stress. They also suggest that smokers use smoking as a convenient way of "manipulating their psychological state," i.e., to reduce boredom or tension.

From this, a derived instantaneous utility function is obtained as

$$U(t) = U[C(t), A(t), \mathbf{Y}(t)], \tag{5}$$

where $\mathbf{Y}(t)$ is a vector including inputs into the production of the composite good and health. At any time, the following will hold:

$$U_C = u_R R_C > 0, \tag{6}$$

$$U_A = u_R R_A + u_H H_A < 0, \tag{7}$$

$$U_{\mathbf{Y}} = u_H H_{\mathbf{Y}} + u_{\mathbf{Z}} \mathbf{Z}_{\mathbf{Y}} > 0, \tag{8}$$

$$U_{CA} = u_{RR} R_C R_A + u_R R_{CA} > 0, \tag{9}$$

and

$$U_{ii} < 0, \quad i = C, A, \mathbf{Y}. \tag{10}$$

Equations (6)–(9) reillustrate the three characteristics of addictive consumption. Equation (6) describes withdrawal since total utility falls if cigarette consumption is reduced. Tolerance is captured by the negative marginal utility of the addictive stock shown in (7), which shows that greater cumulative past consumption lowers current utility, ceteris paribus. Finally, reinforcement is shown by (9), which states that the marginal utility of current consumption is larger as past consumption is greater or that past consumption reinforces current consumption.

The following simple investment function describes the stock accumulation process:

$$\frac{\partial A(t)}{\partial t} = C(t) - \delta A(t), \tag{11}$$

where δ is the constant rate of depreciation of the addictive stock over time. Cigarette consumption at time t can be thought of as gross investment in the addictive stock.

Under the assumption of a time-additive utility function (so that utility is separable over time in C, A, and $\mathbf{Y}$), a constant rate of time preference, σ, and an infinite lifetime, the lifetime utility function is

$$U = \int_0^\infty e^{-\sigma t} U[C(t), A(t), \mathbf{Y}(t)] dt. \tag{12}$$

Rational behavior implies maximization of this function subject to a lifetime budget constraint. If we ignore the allocation of time over the life cycle, treat $\mathbf{Y}(t)$ as a composite good whose price, $P_{\mathbf{Y}}(t)$, is the numeraire, and assume perfect capital markets, the appropriate budget constraint is

$$\int_0^\infty e^{-rt}[\mathbf{Y}(t) + P_C(t)C(t)]dt \le R(0), \tag{13}$$

where $P_C(t)$ is the money price of cigarettes at time t, r is the market interest rate (assumed constant), and $R(0)$ is the discounted value of lifetime income and assets.

Maximizing (12) subject to (11), (13), and an initial stock condition yields the following first-order conditions:

$$U_Y(t) = \mu e^{-(\sigma - r)t} \tag{14}$$

and

$$U_C(t) = \mu \pi_C(t), \tag{15}$$

where

$$\pi_C(t) = P_C(t)e^{-(\sigma - r)t} - \int_t^\infty e^{-(\sigma + \delta)(\tau - t)} U_A(\tau)d\tau. \tag{16}$$

The term $\pi_C(t)$ is the full price of the addictive good and consists of two parts: the money price, $P_C(t)$, appropriately discounted, and the discounted future utility costs of the addictive stock. Since $U_A(t)$ is always negative, the full price of addictive consumption is greater than its money price. Also, the shadow price of the addictive stock is affected by the rate of depreciation on the stock and by the rate of time preference. As depreciation is faster, the shadow price of the stock falls, increasing consumption. Similarly, a higher rate of time preference lowers the full price of the addictive good, cigarettes, and increases its consumption. Finally, the shadow price of the stock rises as the stock increases since $U_{AA} < 0$.

Empirical Framework

To obtain empirically estimable cigarette demand functions, a quadratic utility function in the three arguments $\mathbf{Y}(t)$, $C(t)$, and $A(t)$ is assumed, resulting in linear first-order conditions for $\mathbf{Y}$, C, and A. Also, the individual's rate of time preference is assumed to equal the market rate of interest ($\sigma = r$). The resulting instantaneous utility function is

$$U(t) = b_Y\mathbf{Y}(t) + b_C C(t) + b_A A(t) + \tfrac{1}{2}U_{YY}\mathbf{Y}(t)^2 + \tfrac{1}{2}U_{CC}C(t)^2 + \tfrac{1}{2}U_{AA}A(t)^2 + U_{YA}\mathbf{Y}(t)A(t) + U_{CA}C(t)A(t) + U_{YC}\mathbf{Y}(t)C(t). \tag{17}$$

Maximizing out with respect to $\mathbf{Y}(t)$, converting to discrete time, and using the resulting first-order conditions for $C(t)$ and $A(t)$, one derives the following demand equations:[7]

$$C(t) = \beta_0 + \beta_1 P_C(t) + \beta_2 P_C(t-1) + \beta_3 P_C(t+1) + \beta_4 C(t-1) + \beta_5 C(t+1) \tag{18}$$

and

$$C(t) = \phi_0 + \phi_1 P_C(t) + \phi_2 P_C(t+1) + \phi_3 C(t+1) + \phi_4 A(t). \tag{19}$$

In both equations, current consumption is predicted to be negatively related to the current price of cigarettes but positively related to both past (when included) and future prices.[8] Similarly, current consumption, if the good is addictive, is expected to be positively related to future consumption and, when included, to lagged consumption. Where it enters, no prediction can be made concerning the effect of the addictive stock on current consumption because of the positive effect of reinforcement and the opposing negative effect of an increase in the shadow price of the stock. Finally, these demand equations hold constant the marginal utility of wealth.

These demand equations differ significantly from those obtained when the addictive nature of smoking is ignored or when individuals are assumed to be myopic. When addiction is ignored, current consumption is a function of current price alone, in addition to the exogenous factors influencing demand. All future and past effects are ignored. In myopic models, current demand is a function of current price and a measure of past consumption, but not future consumption and price.[9] Thus the assumptions of rationality and addiction can be tested directly. If smoking is not addictive, then past consump-

[7] Equation (18) provides a more direct test of the addictive model but is difficult to estimate because of the collinearity among prices. Equation (19) provides a less direct test but is easier computationally. The detailed derivation of these demand equations is contained in an appendix available on request.

[8] As Becker et al. (1990) note, the positive past and future price effects seem contradictory since consumptions at different times are complements. However, these equations hold past and future consumption constant, eliminating the mechanism through which past and future prices affect current consumption. However, if past consumption, e.g., is unchanged as past price rises, then some other factor must be leading to an increase in past consumption, offsetting the decrease associated with the increase in price. If past consumption rises for this reason, then current consumption rises.

[9] Myopic, or shortsighted, demand equations are obtained by assuming an infinite rate of time preference. Mullahy (1985) estimates a myopic version of eq. (19) in which ϕ_2 and ϕ_3, the coefficients on the future price of cigarettes and future cigarette consumption, are zero. The demand equations developed above cannot be modified to obtain equations comparable to those resulting from the assumption of myopic behavior, implying that myopic and farsighted behavior are not "observationally equivalent" in the Becker-Murphy model.

tion and price should have no effect on current consumption. Similarly, if smoking is addictive but individuals are myopic, past consumption and price should have a positive impact on current consumption, but future consumption and price should have no effect.[10]

Of particular interest in this work is the long-run price elasticity of demand for cigarettes. To estimate this elasticity, assume that, in the long run, a steady-state level of consumption will be reached that serves to replace depreciation on the addictive stock ($C^* = \delta A^*$, where A^* is the optimal level of the addictive stock). An anticipated permanent rise in price changes consumption in each period, as well as the optimal stock, and a new steady-state equilibrium is achieved. The resulting long-run elasticities are

$$\frac{(\partial C^*/\partial P)P}{C^*} = \frac{[(\beta_1 + \beta_2 + \beta_3)/(1 - \beta_4 - \beta_5)]P}{C^*} \tag{20}$$

for equation (18) and

$$\frac{(\partial C^*/\partial P)P}{C^*} = \frac{\{(\phi_1 + \phi_2)/[1 - \phi_3 - (\phi_4/\delta)]\}P}{C^*} \tag{21}$$

for equation (19).

As Becker and Murphy state, the cigarette demand equations derived above are second-order difference equations in current cigarette consumption. The roots of these difference equations are useful in describing the dynamic aspects of cigarette consumption and will be positive if and only if cigarettes are addictive. The assumption of concavity implies that both roots are real. Thus the signs depend on β_4, which is positive when consumption is addictive. The two roots for demand equation (18) are

$$\lambda_1 = \frac{1 - (1 - 4\beta_4\beta_5)^{1/2}}{2\beta_4}, \quad \lambda_2 = \frac{1 + (1 - 4\beta_4\beta_5)^{1/2}}{2\beta_4}. \tag{22}$$

Similar equations are derived for equation (19) by replacing β_4 with ϕ_4/δ and β_5 with ϕ_3. The smaller of the two roots, λ_1, gives the change in current consumption resulting from a shock to future consumption. The inverse of the larger root, λ_2, shows the impact of a shock to past consumption on current consumption. These shocks result

[10] Habit also appears to be distinguished from addiction by the complementarity of future and current consumption. Habit may result in the complementarity of past and current consumption but does not imply that increases in future consumption will lead to increases in current consumption. Mullahy's (1985) estimates from a myopic model imply that smoking is an addictive behavior. Becker et al. (1990), using a pooled data set of the states of the United States over time, find that smoking is addictive and that individuals do not behave myopically. The estimates below are the first to test the rational addiction model using micro data.

from a change in any factor affecting the demand for cigarettes, including changes in past or future cigarette prices.

Data

Cigarette consumption data from the second National Health and Nutrition Examination Survey are used to estimate the cigarette demand equations. This is a national survey of approximately 28,000 people aged 6 months to 74 years conducted from 1976 to 1980. Individuals were surveyed at 64 sites, consisting of at least one county. Respondents completed detailed questionnaires on their health histories, and most underwent comprehensive physical examinations.

On the basis of the county of residence, real cigarette prices and excise taxes were added to the data.[11] Sizable differences in cigarette prices exist across localities mainly because of differences in excise taxes. This creates an incentive for smokers in high-tax localities to purchase cigarettes in low-tax localities.[12] Failing to account for border crossing would bias the price coefficients toward zero. To capture casual smuggling, an equally weighted average of the "border price" and the local price of cigarettes is used for the cigarette price. The border price is the lowest price for a pack of cigarettes within 25 miles of the county of residence.

In the demand equations above, average daily cigarette consumption is a function of current price, future price, future consumption, and either lagged consumption and price or the addictive stock. To estimate equation (18), consumption in three consecutive periods is required, but only two consecutive periods are available. In the survey, data were collected on current consumption, lagged consumption, and consumption at the time that the individual smoked his or

[11] The price is a weighted-average statewide price for a pack of 20 cigarettes based on the prices of single packs, cartons, and packs from vending machines, inclusive of state sales taxes; the weights are the national proportions of each type of sale. Where applied, local excise taxes were added to the price. Several 1-year lags and leads of prices and taxes were added to the data set under the assumption that the individuals' counties of residence did not change. All prices and taxes are deflated by the national consumer price index and a local price index developed by Mullahy (1985) based on a procedure by Fuchs, Michael, and Scott (1979). Changes in state and local excise tax rates over time, as well as changes in the prices of other goods and services, provide the time-series variation in the real cigarette price and tax data.

[12] This incentive depends on the price difference and the cost of purchasing and transporting cigarettes, and it increases the closer an individual lives to a lower-price locality. An additional problem is that heavier smokers may purchase cartons of cigarettes (lowest price) rather than single packs or packs from vending machines. Given available data, little can be done about this problem. Intertemporal variation in prices results from changes in state and local excise taxes over time as well as the change in the relative price of cigarettes over time. Cigarette prices fell substantially in real terms throughout the 1970s.

her greatest average daily quantity. Also available are the number of years since the individual began smoking regularly and, for former smokers, the number of years that the individual has not smoked.

The following strategy is used to approximate consumption in the third period. Reported current consumption $C(t)$ is treated as future consumption $C^*(t + 1)$, and reported lagged consumption $C(t - 1)$ is treated as current consumption $C^*(t)$. What is now required is an estimate of $C^*(t - 1)$, or what is actually $C(t - 2)$. For those who never smoked, began less than 2 years before their interview, or stopped more than 2 years before their interview, $C^*(t - 1)$ is zero. For those smoking 2 years prior to their interview, maximum consumption is used as a proxy for $C^*(t - 1)$.

To estimate equation (19), current and future consumption and the addictive stock are required. Current and future consumption are obtained as described above. The addictive stock is estimated as follows, under the assumption that the initial stock is zero:

$$A(t) = \sum_{i=0}^{t-1} (1 - \delta)^{t-1-i} C(i). \tag{23}$$

Defining $(1 - \delta)^{t-1-i}$ as $D(i)$ and using the definition for covariance, we can rewrite it as

$$A(t) = \sum_{i=0}^{t-1} C(i)D(i) = t\overline{CD} + t\,\mathrm{cov}[C(i), D(i)]. \tag{24}$$

On the basis of observed lifetime smoking patterns, the covariance is assumed to be relatively small and is ignored. Thus to estimate the stock, mean consumption, the rate of depreciation, and the number of years the individual has smoked are required. For individuals who have never smoked, the stock takes on a value of zero. For smokers, maximum consumption is used as a proxy for mean consumption. Equation (24) is easily modified for former smokers by replacing t with the number of years the individual smoked and multiplying by $(1 - \delta)^q$, where q is the number of years since quitting. Relatively high depreciation rates are assumed, on the basis of the evidence presented in the surgeon general's reports that many of the withdrawal symptoms and physiological effects of smoking disappear shortly after cessation. High depreciation rates do not imply milder addiction, but rather that the consequences of addiction are shorter-lived after cessation.

In each equation, the individual's age, age squared, sex, race, real family income, and educational attainment are included as independent variables. Finally, each equation also includes indicators of marital status and labor force status.

Results

Estimates of demand equations (18) and (19), the long-run price elasticity of demand, and the roots of the difference equation are reported in table 1. Panel A of table 1 contains the estimates for the full sample, panel B contains estimates for the sample of current and former smokers only, and panel C contains estimates for current smokers only. Column 1 contains estimates of equation (18) under the assumption of a 100 percent rate of depreciation, while column 2 contains estimates with no assumption imposed about the rate of depreciation. Columns 3 and 4 contain estimates of equation (19) under the assumption of rates of depreciation of 80 and 60 percent, respectively. Imposing a 100 percent rate of depreciation results in the exclusion of past and future prices from the demand equation and, as a result, is much easier computationally. Making this assumption does not, however, imply that smoking is not addictive since past, current, and future consumption are still expected to be complements.

All equations are estimated using instrumental variables procedures due to the endogeneity of past and future consumption in equation (18) and the addictive stock and future consumption in equation (19).[13] In equation (18), current consumption is a function of one lag of consumption, one lead of consumption, and one lag, current, and one lead of cigarette prices. Thus current consumption is independent of other past and future prices. In the full reduced form, cigarette consumption at any time is a function of all past, current, and future cigarette prices, suggesting that further lags and leads of prices are suitable instruments for lagged and led consumption. Similar arguments can be made for the addictive stock and future consumption in equation (19). Thus the set of instruments includes the exogenous variables affecting consumption, four lags of price, current price, and four leads of price and four lags, current, and four leads of the excise tax on cigarettes. The set of excise taxes is included in an attempt to reduce collinearity problems.

In all but one of the estimated equations the coefficients on prices and past and future consumption conform to the predictions of the

[13] Two problems arise in the estimation of these demand equations: the endogeneity of past and future consumption and the limited dependent variable. Given the theoretical model, emphasis is placed on the endogeneity problem rather than on the limited dependent variable problem. Taking account of both endogeneity and the limited dependent variable is intractable. The use of instrumental variables techniques, in addition to solving the endogeneity problem, also helps to alleviate the errors-in-variables problems associated with using maximum past consumption as a proxy for past consumption and mean consumption in the computation of the addictive stock, at the cost of increasing the variance of these estimators.

TABLE 1

TWO-STAGE LEAST-SQUARES ESTIMATES OF CIGARETTE DEMAND EQUATIONS

Independent Variable	δ = 100% (1)	No Assumed Rate (2)	δ = 80% (3)	δ = 60% (4)
A. Full Sample (N = 14,305)				
Price (t − 1)	. . .	6.856	. . .	. . .
		(1.11)		
Price (t)	−1.671	−12.576	−5.690	−5.167
	(−1.41)	(−1.76)	(−1.40)	(−1.26)
Price (t + 1)	. . .	4.095	4.067	3.594
		(1.01)	(1.02)	(.89)
Addictive stock	. . .	. . .	.357	.257
			(3.15)	(3.04)
Lagged consumption	.486	.516	. . .	. . .
	(3.48)	(3.32)		
Future consumption	.338	.268	.386	.412
	(1.72)	(1.19)	(1.95)	(2.09)
F-statistic	458.19	392.00	435.68	430.50
Long-run price elasticity	−.346	−.274	−.353	−.359
λ_1	.426	.321	.496	.534
λ_2	1.631	1.617	1.745	1.800
B. Ever Smokers (N = 7,946)				
Price (t − 1)	. . .	10.099	. . .	. . .
		(.89)		
Price (t)	−2.976	−19.710	−9.599	−8.535
	(−1.38)	(−1.54)	(−1.32)	(−1.16)
Price (t + 1)	. . .	6.668	6.684	5.655
		(.92)	(.94)	(.78)
Addictive stock	. . .	. . .	.362	.263
			(3.03)	(2.94)
Lagged consumption	.482	.494	. . .	. . .
	(3.25)	(3.18)		
Future consumption	.384	.331	.425	.435
	(2.03)	(1.50)	(2.17)	(2.20)
F-statistic	157.58	138.29	149.57	147.25
Long-run price elasticity	−.450	−.348	−.482	−.467
λ_1	.509	.415	.574	.586
λ_2	1.566	1.609	1.636	1.687
C. Current Smokers (N = 5,111)				
Price (t − 1)	. . .	−3.0694	. . .	. . .
		(−.28)		
Price (t)	−1.683	−10.457	−12.957	−11.784
	(−.59)	(−.67)	(−1.29)	(−1.18)
Price (t + 1)	. . .	12.854	11.250	9.607
		(1.27)	(1.13)	(.97)
Addictive stock	. . .	. . .	.532	.390
			(4.02)	(4.03)
Lagged consumption	.684	.657	. . .	. . .
	(4.11)	(3.83)		
Future consumption	.242	.324	.286	.263
	(1.34)	(1.65)	(1.49)	(1.36)
F-statistic	105.18	93.94	100.85	103.16
Long-run price elasticity	−.296	−.890	−.455	−.322
λ_1	.306	.468	.384	.337
λ_2	1.156	1.054	1.120	1.202

NOTE.—Asymptotic t-ratios are shown in parentheses. The critical asymptotic t-ratios are 1.28 for a one-tailed test and 1.64 for a two-tailed test at the 10 percent level; 1.64 for a one-tailed test and 1.96 for a two-tailed test at the 5 percent level; and 2.33 for a one-tailed test and 2.58 for a two-tailed test at the 1 percent level. The F-statistic for each equation is significant at the 1 percent level. Each equation also includes the individual's age, age squared, the number of years of formal education completed, real family income, and indicators of sex, race and ethnicity, marital status, and labor force status. Results for these variables are available on request.

model. In general, current cigarette consumption is found to be significantly negatively related to the current price of cigarettes. Similarly, when included, past and future prices generally have the anticipated positive effect on current consumption, albeit at somewhat lower significance levels. In most models including both the lagged and led price of cigarettes, the coefficient on past price is larger in magnitude than the coefficient on future price, except for the sample of current smokers, as predicted by the model.[14]

Past and future consumption both have significant positive effects on current consumption. The effect of past consumption is always significant at the 1 percent level, indicating that cigarette smoking is indeed addictive. The coefficient on future consumption is significant at at least the 5 percent level in all but some of the most general models, indicating that individuals are not behaving myopically. In the equations containing both past and future consumption, the coefficient on past consumption is larger in magnitude than that on future consumption, as expected.

Finally, although the model did not predict the direction of the relationship between the addictive stock and current consumption, the addictive stock is found to have a significant positive effect in all equations. This suggests that the reinforcement effect of past consumption is larger than the opposing effect of an increase in the full price of smoking as the stock increases. In general, the estimated coefficients of prices, future consumption, and the alternative measures of past consumption are more significant in the models imposing a higher rate of depreciation on the stock.

The estimated long-run price elasticity of demand for the full sample ranges from −0.36 to −0.27. These are substantially higher than the estimates obtained from nonaddictive demand equations, which range from −0.07 to −0.01 (Chaloupka 1988). Estimated long-run price elasticities of demand for the sample of current and former smokers range from −0.48 to −0.35. Finally, the estimated long-run price elasticity of demand for cigarettes by current smokers, based on estimates consistent with the predictions of the Becker-Murphy theoretical model, ranges from −0.46 to −0.30. The similar ranges for the samples of current and former smokers and current smokers only suggest that the price increase is effective in reducing cigarette consumption by smokers rather than by inducing smoking cessation.

These estimates suggest that doubling the federal excise tax on

[14] The restrictions implied by the theoretical model on the relative size of the past and future price coefficients as well as those on past and future consumption were imposed on some estimates. Imposing these restrictions had little qualitative impact, aside from generally improving the statistical significance of the price and consumption coefficients. These results can be found in Chaloupka (1990).

cigarettes to 32¢ (proposed as part of a deficit reduction package), resulting in an increase of approximately 15 percent in price (assuming a competitive market), would lead, in the long run, to about a 6 percent fall in average cigarette consumption. Harris (1987) suggests that the price increase resulting from an increase in the federal tax could be much greater than the tax increase. Examining the 1983 increase of 8¢ per pack, he finds that prices increased by approximately 16¢. Harris attributes this to producers using the tax increase as a coordinating mechanism for an oligopolistic price increase rather than increases in production costs. If an additional tax increase led to the same type of behavior, the effect of the tax increase on consumption would be even larger.

Examining the estimated roots from the demand equations estimated using the full sample, one sees that a shock that would decrease consumption by 10 percent in the future would lead to a fall of between 3 and 5 percent in current consumption. Similarly, exogenous factors that reduced past consumption by 10 percent would lower current consumption by between 5 and 6 percent. The intertemporal effects of a shock to past or future consumption found among the sample of ever smokers are quite similar to those found among the full sample. Finally, for the sample of current smokers, shocks to past consumption have a larger impact on current consumption than for the other groups, while shocks to future consumption have a smaller effect. This is consistent with the hypothesis that smokers who initiated or continued smoking after the information on its health consequences became widespread may be more myopic than those who quit in response to the spread of information.

The long-run price elasticities of demand presented above are somewhat lower than the comparable elasticities obtained by Becker et al. Their estimates, which range from -0.51 to -0.80, are obtained using a time series of state cross sections covering the period 1956–85. Their estimated roots from the demand equations, however, suggest somewhat weaker intertemporal links in consumption than those obtained from the estimation of comparable demand equations using micro data.

Time Preference and Addiction

The Becker-Murphy model of rational addiction allows for differences in behavior through differences in the rate of time preference. In particular, the model implies that individuals with a greater preference for the present are potentially more subject to becoming addicted than those with a greater preference for the future (Becker and Murphy 1988, p. 682).

Individuals with different levels of education or individuals of different ages are often assumed to have different rates of time preference. Specifically, more educated individuals are thought to have a greater taste for the future than less educated individuals. Similarly, younger individuals are thought to be more present-oriented than older individuals.

To explore the possibility of differences in behavior based on different rates of time preference, separate demand equations are estimated by age and by educational attainment. Estimates for individuals who have completed high school and for those who have not completed high school are found in table 2. Results for those with less than a high school education are presented in panel A, while the comparable estimates for those with at least a high school education are presented in panel B. Similarly, separate estimates for three age groups (ages 17–24, 25–64, and 65–73) are presented in table 3. Panels A, B, and C of table 3 contain the estimates for young adults, individuals aged 25–64, and the elderly, respectively.[15]

The estimates for the various education or age groups tend to support the a priori expectation that less educated or younger individuals behave more myopically than their more educated or older counterparts. In particular, for less educated or younger individuals, past consumption and the addictive stock have significant positive effects on current consumption, whereas future consumption has a statistically insignificant, positive impact. The significant effects of past consumption imply that smoking is addictive. Additionally, the ratio of the estimated coefficients on past consumption to those on future consumption for these groups implies a high rate of time preference, or myopic behavior.

On the other hand, for more educated or older individuals, both past consumption (as measured by either lagged consumption or the addictive stock) and future consumption are found to have statistically significant positive effects on current consumption. This implies that consumption is addictive and that individuals in these groups are behaving less myopically (or more rationally). The estimates imply a relatively low rate of time preference for more educated individuals. It is interesting to note that the elderly are not found to discount the future at all, whereas the rate of time preference implied for individuals aged 25–64 is similar to that obtained for the full sample.

Individuals with fewer years of formal education are relatively re-

[15] Estimates by education and age are presented for the full sample only. Estimates for the sample of current and former smokers and current smokers only yield comparable results and are available on request. Restricted versions of the results presented in tables 2 and 3 can be found in Chaloupka (1990).

TABLE 2

Two-Stage Least-Squares Estimates of Cigarette Demand Equations

Independent Variable	δ = 100% (1)	No Assumed Rate (2)	δ = 80% (3)	δ = 60% (4)
	A. Less than a High School Education (N = 5,665)			
Price (t − 1)	. . .	4.858 (.47)	. . .	. . .
Price (t)	−4.507 (−2.31)	−14.710 (−1.19)	−9.157 (−1.22)	−8.434 (−1.10)
Price (t + 1)	. . .	5.652 (.77)	4.612 (.62)	3.728 (.49)
Addictive stock	. . .	. . .	.535 (3.64)	.389 (3.47)
Lagged consumption	.697 (3.82)	.671 (3.69)	. . .	. . .
Future consumption	.050 (.22)	.084 (.37)	.070 (.29)	.073 (.30)
F-statistic	234.32	220.08	225.47	217.51
Long-run price elasticity	−.618	−.592	−.601	−.587
	B. At Least a High School Education (N = 8,640)			
Price (t − 1)	. . .	1.819 (.24)	. . .	. . .
Price (t)	.232 (.15)	−3.291 (−.38)	−1.067 (−.21)	−.233 (−.04)
Price (t + 1)	. . .	1.712 (.35)	1.281 (.26)	.519 (.11)
Addictive stock	. . .	. . .	.371 (3.39)	.277 (3.34)
Lagged consumption	.471 (3.52)	.479 (3.22)	. . .	. . .
Future consumption	.471 (2.47)	.454 (2.08)	.486 (2.54)	.498 (2.61)
F-statistic	225.10	204.04	214.24	211.72
Long-run price elasticity	.151	.135	.161	.268

Note.—See note to table 1.

sponsive to prices, as illustrated by the estimated long-run price elasticities in the range −0.62 to −0.57. However, more educated individuals are found to be unresponsive to changes in price. This supports the Becker-Murphy hypothesis that more present-oriented individuals will be affected more by the market price of the addictive good than more future-oriented individuals because of the relatively minor role the negative future utility effects of the addiction play in the computation of the full price of addictive consumption for these individuals.

However, this hypothesis is not supported by the estimates obtained for the three age groups. Both young adults (ages 17–24) and the

TABLE 3

Two-Stage Least-Squares Estimates of Cigarette Demand Equations

Independent Variable	δ = 100% (1)	No Assumed Rate (2)	δ = 80% (3)	δ = 60% (4)
	A. Ages 17–24 (N = 2,575)			
Price (t − 1)	. . .	3.667 (.30)	. . .	. . .
Price (t)	.128 (.04)	−15.737 (−1.14)	−12.413 (−1.22)	−12.240 (−1.19)
Price (t + 1)	. . .	12.434 (1.20)	12.192 (1.22)	11.657 (1.16)
Addictive stock	. . .	. . .	.432 (3.19)	.304 (3.00)
Lagged consumption	.617 (3.66)	.570 (3.13)	. . .	. . .
Future consumption	.066 (.30)	.138 (.56)	.198 (.90)	.266 (1.26)
F-statistic	67.64	64.32	70.91	68.47
Long-run price elasticity	.016	.050	−.034	−.103
	B. Ages 25–64 (N = 8,997)			
Price (t − 1)	. . .	13.264 (1.50)	. . .	. . .
Price (t)	−2.950 (−1.86)	−18.952 (−1.75)	−5.050 (−.89)	−4.603 (−.81)
Price (t + 1)	. . .	2.881 (.50)	2.156 (.40)	1.853 (.34)
Addictive stock	. . .	. . .	.382 (2.84)	.266 (2.71)
Lagged consumption	.506 (2.96)	.566 (2.93)	. . .	. . .
Future consumption	.285 (1.25)	.191 (.77)	.320 (1.44)	.369 (1.72)
F-statistic	213.21	191.35	225.76	226.23
Long-run price elasticity	−.437	−.315	−.443	−.454
	C. Ages 65–73 (N = 2,733)			
Price (t − 1)	. . .	−3.496 (−.38)	. . .	. . .
Price (t)	.019 (.01)	.761 (.07)	−2.435 (−.36)	−1.975 (−.29)
Price (t + 1)	. . .	2.687 (.42)	2.569 (.40)	2.283 (.35)
Addictive stock	. . .	. . .	.345 (4.19)	.252 (4.12)
Lagged consumption	.430 (4.14)	.427 (4.10)	. . .	. . .
Future consumption	.446 (3.53)	.457 (3.57)	.443 (3.48)	.449 (3.51)
F-statistic	73.14	65.67	68.50	66.74
Long-run price elasticity	.011	−.029	.075	.166

Note.—See note to table 1.

elderly (ages 65–73) are found to be insensitive to changes in price, whereas the rest of the sample (ages 25–64) shows a significant long-run response to a change in price, as indicated by the estimated long-run price elasticities in the range −0.46 to −0.31. This is in contrast to the estimates obtained by Lewit and Coate (1982) and Lewit, Coate, and Grossman (1981), who find younger individuals more responsive to price than older individuals. Nevertheless, these estimates may also be compatible with the predictions of the model. Becker and Murphy (1988, p. 685) show that more addicted individuals will be more responsive in the long run to changes in the price of the addictive good than less addicted individuals. They also state that "people who . . . become old are less likely to be strongly addicted to harmful goods" (p. 684), implying that they will be less responsive in the long run to changes in price. Similarly, younger individuals will have smaller accumulated stocks of past consumption, implying that they too will be less addicted and, hence, be less responsive to changes in price.

Conclusions

This paper develops cigarette demand equations derived from the Becker-Murphy (1988) model of rational addiction and estimates these demand equations using data for individuals in the United States. In general, the estimates support the hypotheses that cigarette smoking is an addictive behavior and that individuals do not behave myopically. Furthermore, the estimates imply that accounting for the addictive aspects of consumption is important in understanding individuals' cigarette consumption.

The estimates presented above support the hypothesis that increasing the price of cigarettes by increasing excise taxes on them would effectively reduce smoking. Doubling the federal excise tax to 32¢ (proposed as part of a deficit reduction program), increasing price by approximately 15 percent (assuming a competitive market), would lead, in the long run, to a 4–6 percent fall in consumption. This tax increase would raise price and reduce consumption even more if cigarette producers use the tax increase as a coordinating mechanism for an oligopolistic price increase.

Further support for the Becker-Murphy model is found in the estimation of separate demand equations for subsamples based on education or age. The strong effects of past consumption and weak effects of future consumption among younger or less educated individuals support the a priori expectation that these groups behave myopically. Similarly, the strong effects of both past and future consumption among older or more educated individuals indicate more farsighted behavior as anticipated. Finally, the relative long-run price elasticities found for the various subsamples support the Becker-Murphy hypotheses that more addicted (more myopic) individuals will be more responsive, in the long run, to changes in price than less addicted (less myopic) individuals.

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