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ABSTRACT

We use a framework suggested by a model of rational addiction to analyze empirically the demand for cigarettes. The data consist of per capita cigarettes sales (in packs) annually by state for the period 1955 through 1985. The empirical results provide support for the implications of a rational addiction model that cross price effects are negative (consumption in different periods are complements), that long-run price responses exceed short-run responses, and that permanent price effects exceed temporary price effects. A 10 percent permanent increase in the price of cigarettes reduces current consumption by 4 percent in the short run and by 7.5 percent in the long run. In contrast, a 10 percent increase in the price for only one period decreases consumption by only 3 percent. In addition, a one period price increase of 10 percent reduces consumption in the previous period by approximately .7 percent and consumption in the subsequent period by 1.5 percent. These estimates illustrate the importance of the intertemporal linkages in cigarette demand implied by rational addictive behavior.

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I. Introduction and Summary

Becker and Murphy (1988) develop a theoretical model of rational addiction and outline its key empirical predictions. This paper uses that framework to analyze empirically the demand for cigarettes. The data consist of per capita cigarette sales (in packs) annually by state for the period 1955 through 1985. The empirical results indicate that smoking is addictive.

The Becker-Murphy model follows Stigler and Becker (1977), Iannaccone (1986), Ryder and Heal (1973), Boyer (1978, 1983), and Spinnewyn (1981) by considering the interaction of past and current consumption in a rational model. The main feature of these models is that past consumption of some goods influences their current consumption by affecting the marginal utility of current and future consumption. Greater past consumption of harmfully addictive goods such as cigarettes stimulates current consumption by increasing the marginal utility of current consumption more than the present value of the marginal harm from future consumption. Therefore, past consumption is reinforcing for addictive goods. The Becker-Murphy model has several empirical implications for addictive behavior that include a bimodal distribution of consumption, quitting by cold turkey, a negative cross effect, or complementarity, between the price of the good at one time and its consumption at another time, larger long-run than short-run elasticities of demand, larger responses to anticipated than unanticipated prices changes, and larger responses to permanent than temporary price changes.

This paper mainly tests the effect of addiction on the response of cigarette consumption to a change in cigarette prices. We examine whether lower past and future prices for cigarettes raise current cigarette consumption. The empirical results support the implication of addictive behavior that cross price effects are negative, and that long-run responses exceed short-run responses.

For example, we find that a 10 percent permanent increase in the price of cigarettes reduces current consumption by 4 percent in the short run and by 7.5 percent in the long run. In contrast, a 10 percent increase in price for only one period decreases consumption by only 3 percent. In addition, a one period price increase of 10 percent decreases consumption in the previous period by approximately .7 percent and consumption in the subsequent period by 1.5 percent. These estimates illustrate the importance of the intertemporal linkages in cigarette demand implied by addictive behavior.

In myopic models of addictive behavior, past consumption stimulates current consumption, but individuals ignore the future when making consumption decisions. We show that these models typically have negative effects of past prices on current consumption, but no effect of anticipated future prices on current consumption. Since rational models always exhibit the symmetry of (compensated) cross price effects implied by optimizing behavior, testing for the effects of future prices on current consumption distinguishes rational models of addiction from myopic models. The results strongly reject myopic behavior and generally support the model of rational addiction.

The Becker-Murphy model also relates the consumption of addictive goods to stressful events, such as unemployment and divorce. We test these implications and evaluate the effects of education and religious affiliation by using state- and time-specific measures of divorce, unemployment, the fraction of the population with a high school degree, and measures of religion. The results for stressful events are mixed. Greater divorce rates are associated with higher levels of cigarette consumption. However, cigarette consumption is basically unrelated to state unemployment rates, perhaps because state differences are mainly anticipated permanent differences in unemployment rather than unexpected temporary differences that are more stressful.

The cigarette industry raised the price of cigarettes in 1982 as well as in 1983 when the federal excise tax on cigarettes increased. Apparently, the industry also raised cigarette prices in the 1980s in anticipation of a continuing fall in smoking. Such pricing is inconsistent with perfect competition, but it is consistent with monopoly power in the cigarette industry if cigarette smoking is addictive. Since other evidence also suggests that the industry has monopoly power, this pricing policy is further testimony to the large effect of addictive behavior on aggregate cigarette consumption.

II. The Basic Model

Most empirical analyses of consumption deal with single period models or implicitly assume time-separable utility. By definition, single period models cannot deal with the dynamics of consumption behavior, and the usual two stage budgeting property of time-separable models precludes any dynamics other than those arising from dynamic wealth changes and aggregate consumption effects. Since addictions imply linkages in consumption of the same good over time, it is essential to relax the additive separability assumption to model consumption of addictive goods.

The simplest way to relax the separability assumption is to allow utility in each period to depend on consumption in that period and consumption in the previous period. In particular, following Boyer (1978, 1983), we consider a model with two goods and current period utility in period t given by a concave utility function

$$U(Y_t, C_t, C_{t-1}, e_t) \quad (1)$$

Here C_t is the quantity of cigarettes consumed in period t, C_{t-1} is the quantity of cigarettes consumed in period t-1, Y_t is the consumption of a composite commodity in period t, and e_t reflects the impact of unmeasured life cycle variables on utility. Individuals are assumed to be infinite lived and maximize the sum of lifetime utility discounted at the rate r.

If the composite commodity, Y, is taken as numeraire, if the rate of interest is equal to the rate of time preference, and if the price of cigarettes in period t is denoted by P_t, then the consumer's problem is

$$\text{Max} \sum_{t=1}^{\infty} \beta^{t-1} U(C_t, C_{t-1}, Y_t, e_t) \quad (2)$$

such that $C_0 = C^0$ and

$$\sum_{t=1}^{\infty} \beta^{t-1} (Y_t + P_t C_t) = A^0 ,$$

where $\beta = 1/(1+r)$. We ignore any effect of C on earnings, and hence on the present value of wealth (A^0), and we also ignore any effect of C on the length of life. The initial condition for the consumer in period 1, C^0, measures the level of cigarette consumption in the period prior to that under consideration.

The associated first-order conditions are

(3a) $$U_y(C_t, C_{t-1}, Y_t, e_t) = \lambda$$

(3b) $$U_1(C_t, C_{t-1}, Y_t, e_t) + \beta U_2(C_{t+1}, C_t, Y_{t+1}, e_{t+1}) = \lambda P_t \ .$$

Equation (3a) is the usual condition that the marginal utility of consumption in each period, U_y, equals the marginal utility of wealth, λ. Equation (3b) implies that the marginal utility of current cigarette consumption, U_1, plus the discounted marginal effect on next period's utility of today's consumption, U_2, equals the current price multiplied by the marginal utility of wealth. In the case of a harmfully addictive good such as cigarettes, U_2 is negative, although the model that we develop simply assumes that this term is not zero. That is, the predictions contained in this section are also valid in the case of beneficial addiction ($U_2 > 0$).

Since the marginal utility of wealth, λ, is constant over time, variations in the price of cigarettes over time trace out marginal utility of wealth-constant demand curves for Y and C. In the time-separable case, these demand curves depend only on the current price, P_t, and the marginal utility of wealth, but with nonseparable utility, they depend on prices in all periods through the effects of past and future prices on past and future consumption.

To illustrate, consider a utility function that is quadratic in Y_t, C_t, and e_t. The first-order conditions become

(4a) $$U_y + U_{yy}Y_t + U_{y1}C_t + U_{y2}C_{t-1} + U_{ye}e_t = \lambda$$

(4b) $$U_1 + U_{1y}Y_t + U_{11}C_t + U_{12}C_{t-1} + U_{1e}e_t t$$
$$+ \beta(U_2 + U_{2y}Y_{t+1} + U_{12}C_{t+1} + U_{22}C_t + U_{2e}e_{t+1}) = \lambda P_t$$

Equation (4a) can be solved for Y_t in terms of λ and C_t:

$$(5) \qquad Y_t = \frac{\lambda}{U_{yy}} - \frac{1}{U_{yy}} (U_y + Y_{y1}C_t + U_{22}C_{t-1} + U_{ye}e_t) \quad .$$

If equation (5) is used to substitute for Y_t in equation (4b), we get a linear difference equation that determines current cigarette consumption as a function of past and future cigarette consumption, the current price of cigarettes, P_t, and the shift variables e_t and e_{t+1}:

$$(6) \qquad C_t = \theta C_{t-1} + \beta\theta C_{t+1} + \theta_0 + \theta_1 P_t + \theta_2 e_t + \theta_3 e_{t+1} \, ,$$

where

$$\theta = \frac{-(U_{12}U_{yy} - U_{1y}U_{2y})}{(U_{11}U_{yy} - U_{1y}^2) + \beta(U_{22}U_{yy} - U_{2y}^2)}$$

$$\theta_0 = \frac{(U_y - \lambda)(U_{1y} + \beta U_{2y}) - (U_1 + \beta U_2)}{(U_{11}U_{yy} - U_{1y}^2) + \beta(U_{22}U_{yy} - U_{2y}^2)}$$

$$\theta_1 = \frac{U_{yy}\lambda}{(U_{11}U_{yy} - U_{1y}^2) + \beta(U_{22}U_{yy} - U_{2y}^2)} < 0$$

$$\theta_2 = \frac{-(U_{yy}U_{1e} - U_{1y}U_{ey})}{(U_{11}U_{yy} - U_{1y}^2) + \beta(U_{22}U_{yy} - U_{2y}^2)}$$

$$\theta_3 = \frac{-\beta(U_{yy}U_{2e} - U_{2y}U_{2e}}{(U_{11}U_{yy} - U_{1y}^2) + \beta(U_{22}U_{yy} - U_{2y}^2)} \, .$$

Since θ_1 is negative by concavity of U, equation (6) implies that increases in the current price decrease current consumption, C_t, when the marginal utility of wealth is fixed. The effects of changes in future or past consumption on current consumption depend only on the sign of the term θ. When θ is positive, forces that increase past or future consumption, such as lower past or future cigarette prices, also increase current consumption. In contrast, when θ is negative, greater past or future consumption decreases current consumption. Hence current and past consumption are complements, if and only if,

$$(7) \qquad \theta = \frac{-(U_{12}U_{yy} - U_{1y}U_{2y})}{(U_{11}U_{yy} - U_{1y}^2) + \beta(U_{22}U_{yy} - U_{2y}^2)} > 0 \quad .$$

Since past consumption reinforces current consumption when behavior is addictive, we say that a good is addictive if and only if an increase in past consumption leads to an increase in current consumption holding current prices, e_t, e_{t+1}, and the marginal utility of wealth fixed. A good is more addictive when the reinforcement from past consumption is greater. This definition means that a good is addictive if $\theta > 0$, and the degree of addiction is greater when θ is larger.

Equation (6) is the basis of the empirical analysis in this paper. Cigarette consumption in period t is a function of cigarette consumption in periods t-1 and t+1, the current price of cigarettes, P_t, and the unobservables e_t and e_{t+1}. Ordinary least squares estimation of equation (6) would lead to biased estimates of the parameters of interest. The unobservable errors, e_t, that affect utility in each period are likely to be serially correlated; even if these variables are uncorrelated, the same error e_t directly affects consumption at all dates through the optimizing behavior implied by equation (6). Positive serial correlation in the unobserved effects incorrectly imply that past and future consumption positively affect current consumption, even when the true value of θ is zero.

Fortunately, the specification in equation (6) suggests a way to solve this endogeneity problem that is similar to the estimation strategy proposed by Hansen (1982) and McCallum (1979). Equation (6) implies that current consumption is independent of past and future prices when C_{t-1} and C_{t+1} are held fixed, that any effect of past or future prices must come through their effects on C_{t-1} or C_{t+1}. Provided that the unobservables are uncorrelated with prices in these periods, past and future prices are logical instruments for C_{t-1} and C_{t+1}, since past prices directly affect past consumption, and future prices directly affect future consumption. Therefore, our empirical strategy is to estimate θ and θ_1, the main parameters of equation (6), by using past and future price variables as instruments for past and future consumption.

These estimates can be used to derive short- and long-run demand elasticities for cigarettes, and cross price elasticities between cigarette consumption at different points in time that test how important addiction is to aggregate cigarette consumption. It is intuitively clear from equation (6) that a fall in the current price of cigarettes, P_t, increases current consumption, C_t, which will increase cigarette consumption at time t+1 when θ is positive. Similarly, if this fall in P_t is anticipated in t-1, the rise in C_t also stimulates a rise in consumption at time t-1. In addition, a permanent fall in price has a larger effect on current consumption than does a temporary fall in price, since a permanent fall in price combines a fall in the current price with a fall in all future prices.

These and other results can be seen more formally by solving the second-order difference equation in (6). The dynamics of the system are determined by the roots of the quadratic equation

$$(8) \qquad -\theta\phi^2 + \phi - \theta\beta = 0 .$$

The two roots are

$$(9) \qquad \phi_1 = \frac{1 - (1 - 4\theta^2\beta)^{1/2}}{2\theta} \qquad \phi_2 = \frac{1 + (1 - 4\theta^2\beta)^{1/2}}{2\theta} ,$$

with $4\theta^2\beta < 1$ by concavity. These roots are both real and of the same sign as θ. Both roots are positive if and only if cigarettes are addictive ($\theta > 0$); otherwise, both roots will be zero or negative. The general solution to equation (6) is

$$(10) \qquad C_t = \frac{1}{\theta\phi_1[\phi_2-\phi_1]} \sum_{s=1}^{\infty} \phi_1^s h(t + s) + \frac{1}{\theta\phi_1[\phi_2-\phi_1]} \sum_{s=0}^{\infty} \phi_2^{-s} h(t - s)$$

$$+ \frac{1}{\phi_2^t} \left(C^0 - \frac{1}{\theta\phi_1[\phi_2- \phi_1]} \sum_{s=1}^{\infty} \phi_1^s h(s) \right) ,$$

where

$$h(t) = \theta_0 + \theta_1 P_{t-1} + \theta_2 e_{t-1} + \theta_3 e_t .$$

Equation (10) determines the sign of the effects of changes in the price of cigarettes in period τ on cigarette consumption in period t. These effects, which are temporary in nature since prices in other periods are held constant, are

(11a) $$\left.\frac{dC_t}{dP_\tau}\right|_{\tau>t} = \frac{\theta_1\phi_1^{\tau-t}}{\theta[\phi_2-\phi_1]}\left[1-\left(\frac{\phi_1}{\phi_2}\right)^t\right] \lesseqgtr 0 \text{ as } \theta \gtreqless 0$$

(11b) $$\left.\frac{dC_t}{dP_\tau}\right|_{\tau<t} = \frac{\theta_1\phi_2^{\tau-t}}{\theta[\phi_2-\phi_1]}\left[1-\left(\frac{\phi_1}{\phi_2}\right)^\tau\right] \lesseqgtr 0 \text{ as } \theta \gtreqless 0$$

(11c) $$\frac{dC_t}{dP_t} = \frac{\theta_1}{\theta[\phi_2-\phi_1]}\left[1-\left(\frac{\phi_1}{\phi_2}\right)^t\right] < 0 .$$

Clearly the sign of the cross price effect depends entirely on the sign of θ. The goods in any two consecutive periods are complements (i.e., negative cross price effects) if and only if θ is positive.

The temporary current or own price effect given by equation (11c) depends on t and rises in absolute value as t rises. This is because t measures the number of years in advance that a change in P_t is anticipated. If t on the right-hand side of the equation equals one, the price change is not anticipated until period t. This gives the completely unanticipated own price effect. If t approaches infinity, the price change is fully anticipated as of the planning date. Thus, the limit of (11c) as t goes to infinity yields the fully anticipated temporary own price effect.

Along the same lines, the limit of equation (11a) as t on the right-hand side of the equation goes to infinity gives the effect of a fully anticipated temporary change in P_{t+1} ($\tau = t+1$). If t is set equal to one in the same equation, one obtains the effect of a change in future price that is not anticipated until one period before it occurs. Finally, the limit of equation

(11b) as τ goes to infinity shows the effect of a fully anticipated temporary change in P_{t-1} ($\tau = t-1$). The corresponding unanticipated past price effect results when τ on the right-hand side of (11b) is set equal to one.

If a temporary increase or decrease in P_t or P_{t+1} is not anticipated until period t, C_{t-1} remains the same. If a temporary change in P_{t-1} is not anticipated until period t-1, consumption in prior periods does not change. Since past consumption is held constant in the case of unanticipated price changes and since an increase in past consumption raises current consumption given addiction, anticipated price effects are larger in absolute value than unanticipated price effects. Based on equation (11), the ratio of a fully anticipated temporary price effect to the corresponding unanticipated price effect is $\phi_2/(\phi_2 - \phi_1)$.

In addition to the own price and cross price effects given in (11a)-(11c) and to the difference between anticipated and unanticipated price effects, we are interested in the difference between long- and short-run responses to permanent price changes. These differences can be derived directly from equation (10) as well. The effect on consumption in period t of a permanent reduction in price beginning in period t, which we denote dC_t/dP_t^*, is given by

$$(12) \qquad \frac{dC_t}{dP_t^*} = \frac{\theta_1[1 - (\phi_1/\phi_2)^t]}{\theta(1 - \phi_1)(\phi_2 - \phi_1)} \quad .$$

Once again, t on the right-hand side of equation (12) shows the number of periods in advance that the price change is anticipated. With t equal to one, the equation gives the effect on current consumption of a completely unanticipated permanent reduction in price. This effect is

(13) $$\frac{dC_t}{dP_t^*} = \frac{\theta_1}{\theta(1 - \phi_1)\phi_2} .$$

Equation (13) shows the short-run price effect, defined as the impact on consumption of a reduction in current price and all future prices, with past consumption held constant.

Finally the effect of a permanent reduction in price in <u>all</u> periods on consumption in period t is

(14) $$\frac{dC_t}{dP} = \frac{\theta_1\phi_2^{-t}}{\theta(\phi_2 - \phi_1)}\left[\frac{\phi_2^t - 1}{1 - \phi_2} - \frac{(1 - \phi_1^t)}{1 - \phi_1}\right] + \frac{\theta_1[1-(\phi_1/\phi_2)^t]}{\theta(1-\phi_1)(\phi_2-\phi_1)} .$$

The limit of equation (14) as t goes to infinity equals the long-run effect of a permanent reduction in price:

(15) $$\frac{dC_\infty}{dP} = \frac{\theta_1}{\theta(1-\phi_1)(\phi_2-1)} .$$

Equations (15) and (13) show that the long-run response to a permanent price reduction exceeds the short-run response by the factor $\phi_2/(\phi_2 - 1)$. This exceeds one if and only if $\phi_2 > 1$, which is equivalent to having $\theta > 0$. In addition, the long-run price effect exceeds the fully anticipated temporary own price effect by the factor $[(\phi_2 - \phi_1)]/[(1 - \phi_1)(\phi_2 - 1)]$.

The differences between long-run and short-run, temporary and permanent, and anticipated and unanticipated, price changes are greater when there is a greater degree of addiction or complementarity; i.e., when θ is larger. The cross price effects, and hence the differences between these various elasticities are small when θ is close to zero. The simplicity of a time-separable model then would make it superior to the addiction model. However, if θ is quite different from zero, a time-separable model is likely to give highly misleading predictions about both the short-run and long-run response of consumption to changes in taxes and prices.

III. A Myopic Model of Addiction

While the model presented in Becker and Murphy (1988) shows that addictive behavior can be successfully modeled in a rational choice framework, many previous researchers have considered nonrational or myopic models of addition and habit formation (see, for example, Pollak 1970, 1976 or Yaari 1977). We cannot hope to develop an empirical framework that encompasses the structures used in all nonrational models, but this section presents a myopic model related to those suggested in the literature. Even this sample model highlights an important empirical distinction between myopic and nonmyopic models.

To maintain as much similarity to the previous model as possible, we use the same utility function and the same assumptions about the goods Y and C. The key distinction is that myopic individuals fail to consider the impact of current consumption on future utility and future consumption. Analytically, this corresponds to individuals using the first-order conditions

$$U_y + U_{yy} Y_t + U_{y1}C_t + U_{y2}C_{t-1} + U_{ye}e_t = \lambda \tag{16a}$$

$$U_1 + U_{1y} Y_t + U_{11}C_t + U_{12} C_{t-1} + U_{1e}e_t{}^t = \lambda P_t . \tag{16b}$$

Equation (16a) is the same as that used in the previous section since the consumption of Y has no effects on future utility. However, when individuals behave myopically, the first-order condition for cigarette consumption changes significantly. In contrast to the first-order condition, (4b), in the previous section, equation (16b) does not contain the future effect βU_2.

Differences between myopic and rational behavior are highlighted by solving (16a-b) for C_t, as we did in the previous section. Solving for Y_t using (16a), and substituting the result into equation (16b), we get the myopic equivalent of equation (6). The major difference between equation (6) and the myopic equation is that the latter is entirely backward looking. Current consumption depends only on current price, lagged consumption, the marginal utility of wealth, and current events. Current consumption is independent of both future consumption, C_{t+1}, and future events, e_{t+1}. Because of these distinctions, myopic models and rational models have different implications about responses to future changes. In particular, rational addicts increase their current consumption when future prices are expected to fall, but myopic addicts do not.

Empirically, the difference between the two equations provides a clear test between rational and myopic addiction. Myopic behavior implies that the coefficient on instrumented future consumption should be zero, while the rational model implies that it should have the same sign as the coefficient on lagged consumption (the sizes differ only by the discount factor). Future price (and consumption) changes have no impact on the current consumption of a myopic addict, but they have significant effects on the current consumption of a rational addict.

IV. Data and Empirical Implementation

The data consist of a time series of state cross sections covering the period from 1955 through 1985. We assume that aggregate cigarette consumption in these data reflects the behavior of a representative consumer. Table 1 contains definitions, means, and standard deviations of the primary variables in the data set. A detailed description of the variables and their sources appears in the first section of the appendix. All prices, taxes, and income measures were deflated to 1967 dollars with the consumer price index for all goods. State- and year-specific cigarette prices were obtained from the Tobacco Tax Council (1986). The consumption data were taken from the same source and pertain to per capita tax-paid cigarette sales (in packs). A number of studies have used these data to estimate cigarette demand functions. The most recent one, which contains a review of past research, is by Baltagi and Levin (1986). None of them contain the refined measures of incentives for short- and long-distance smuggling of cigarettes across state lines (see below) that we employ or consider how addiction affects the estimates.

Cigarette sales are reported on the basis of a fiscal year running from July 1 through June 30. Therefore, real per capita income also is on a fiscal year basis, and the retail price of a pack of cigarettes pertains to January of the year at issue. The price is given as a weighted-average price per pack, using national weights for type of cigarette (regular, king, 100 mm) and type of transaction (carton, single pack, machine). It is inclusive of federal, state, and municipal excise taxes and state sales taxes imposed on cigarettes.

There are 1,581 potential observations in the data set (50 states and the District of Columbia times 31 years). Missing sales and price data in nine states in certain years reduce the actual number of observations to 1,516. There are no gaps in the state-specific price and sales series. That is, if one of these variables is reported in year t, it is reported in all future years. Note that states are deleted only in years in which data are missing.

The existence of state excise taxes on cigarettes provides much of the empirical leverage required to estimate the parameters of cigarette demand. Cigarette tax rates vary greatly across states at a point in time and within a given state over time. For example, for the period of our sample, the average tax level (in 1967 dollars) is 6.4 cents per pack or about 21 percent of the average retail price of 30 cents. The range of tax rates also is substantial. A rate one standard deviation above the mean is 6 cents higher than a rate one standard deviation below the mean. This difference is 20 percent of the average retail price. The variation in retail prices due to differences in taxes across states and over time within a state helps identify the impact of price changes on consumption.

The state and time-series data have several pitfalls. In particular, the diffusion of new information about the health hazards of smoking may have greatly affected smoking over the period of our sample. To incorporate such effects, we use time-specific dummy variables. Unfortunately, the coefficients of these time variables also contain the responses in aggregate consumption to national changes in the price of cigarettes.

In addition, states differ in demographic composition, income, and other variables that are correlated with smoking. Our estimates of price effects would be biased if these differences are also correlated with tax or price differentials across states. To mitigate this bias, we estimate all specifications with real per capita income and most specifications with fixed state effects. In a few models we replace the set of dichotomous variables for each state except one with the education, divorce, religion, and unemployment measures listed in Table 1. These four variables are too collinear with the state dummies to be included in the same regression.[1]

The measure of cigarette smoking refers to per capita sales within states, which can differ from per capita consumption within states. When adjacent states have significantly different tax policies, there is an obvious incentive to smuggle cigarettes across states. We constructed three measures that attempt to correct for both short-distance and long-distance smuggling. The short-distance smuggling variable uses tax differentials between surrounding states together with information on the proportion of individuals living within 20 miles of neighboring states that have lower cigarette tax rates (for imports) or higher tax rates (for exports). The long-distance smuggling measure uses the difference between a state's tax and the tax in each of the states of Kentucky, North Carolina, and Virginia. These three states account for almost all of the cigarettes produced in the U.S. based on value added and had the three lowest excise tax rates in the country starting in fiscal 1967. The smuggling variables are described in greater detail in the appendix.

V. Empirical Results

The major implication of the addiction model is that cigarette consumption decisions are linked over time. In particular, both past and future consumption affect current consumption. Since future and past prices have direct effects on future and past consumption, future and past prices indirectly impact current consumption when current prices are held fixed. Both future and past prices negatively affect the current consumption of rational addicts. Table 2 checks the implication of the model that the coefficients on all past and future prices in equation (10) should be negative if cigarettes are addictive.

The first two columns of Table 2 give estimates of a standard cigarette demand function that includes only current price in addition to income, dummy variables for years, the smuggling variables and state dummies (column 1) or state demographic controls (column 2). The implied price elasticity at the mean of -.71 is similar to the estimates in other studies. The highly significant effects of the smuggling variables (ℓdtax, sdimp, and sdexp) indicate the importance of interstate smuggling of cigarettes.

The switch from state dummies in column 1 to state demographic variables in column 2 lowers the R-square of the regression substantially, but it has almost no effect on the price and income effects. This indicates that the correlation between prices and omitted state effects may not be large. Higher divorce rates are positively associated with smoking. This is consistent with higher divorce rates causing (or being caused by) greater tension levels that increase the demand for smoking. Other explanations are also possible. These estimates confirm the finding by other researchers that more educated people smoke less (for example, Lewit and Coate 1982). Per capita consumption of cigarettes is lower in states where Mormons are more prevalent and higher in states where Catholics are more prevalent. The state unemployment rate is essentially unrelated to smoking.

The regressions in columns 3 and 4 include one lag and one lead of the cigarette price in addition to the other variables in columns 1 and 2.[2] These coefficients are not consistent estimates of the true cross price effects due to the omission of the other prices implied by equation (10), which surely are correlated with the included prices.[3] Nevertheless, they suggest that past and future cigarette prices are important determinants of current cigarette consumption in the direction implied by rational addiction. The F test that past and future prices have no effect, valid under the null hypothesis that cigarettes are not addictive, strongly rejects this hypothesis in both specifications. The F-statistics are 10.7 and 34.8 for the models in columns 1 and 2, respectively.[4]

Table 3 tests the addictive model more directly by estimating the following equation (disturbance term omitted) with various instrumental sets:

$$(17) \qquad C_t = \theta_p C_{t-1} + \theta_F C_{t+1} + \theta_0 + \theta_1 P_t \quad .$$

The instruments used in column 1 consist of past and future prices (P_{t-1} and P_{t+1}, respectively) plus the other explanatory variables in the model.[5] Column 2 adds the current and one period lag values of the state cigarette tax to the instruments, column 3 further adds the one period lead value of the tax, and column 4 further adds two additional lags of the price and tax variables. State excise taxes are used as instruments in some of the models because consumers may have more knowledge about taxes, especially future taxes, than about future prices. A complete list of instruments for all models is given in the second section of the appendix

The estimated effects of past and future consumption on current consumption are positive in the first four models in Table 3, and the estimated price effects are significantly negative in all cases. The final column replaces the state dummies with the state demographic controls used in columns 2 and 4 of Table 2. The estimated effects are quite similar to those obtained with state dummies and also show positive and large impacts of past and future consumption on current consumption.[6]

The roots of the quadratic equation [see equation (8)]

$$-\theta_p \phi^2 + \phi - \theta_F = 0 \qquad (18)$$

determine the dynamic response of consumption to various states, where θ_p is the coefficient on past consumption and θ_F is the coefficient on future consumption. The smaller root, ϕ_1, gives the change in current consumption generated by shocks to future consumption, dC_t/dC_{t+1}, while the inverse of the larger root gives the effect of shocks to past consumption on current consumption. Table 4 presents estimates of these roots implied by each of the five models in Table 3 (standard errors are given in parentheses). The range of estimates implies that a 10 percent increase in current consumption due perhaps to a fall in the current price of cigarettes will increase next period's consumption by between 4.2 and 5.5 percent, and a 10 percent increase in future consumption (due perhaps to a fall in future price) will increase current consumption by between 1.4 and 2.6 percent.[7]

Table 5 uses the estimates from Table 3 to compute the elasticity of cigarette consumption with respect to various price changes. Estimates of the long-run response to a permanent change in price based on equation (15) in the first row range from -.74 to -.80, and are about 5 to 10 percent larger than the estimates in Table 2. More important are the significant cross price effects. A ten percent unanticipated reduction in current price leads to an increase of between 1.5 and 1.6 percent in next period's consumption [see row 5, which is based on equation (11b) with τ and τ-t on the right-hand side equal to one and minus one, respectively] and to a .5 to .9 percent increase in the previous period's consumption [see row 4, which is based on equation (11a) with t and τ-t on the right-hand side both equal to one].

These estimates imply that a ten percent decline in cigarette prices causes a short-run increase in cigarette consumption of 4 percent [see row 6, which is based on equation (13)], which is only about 50 percent of the estimated long-run response of 7.5 percent. Finally, a 10 percent temporary increase in the current price of cigarettes would decrease current consumption by 3.5 percent if it is anticipated [see row 2, which is based on equation (11a) with t on the right-hand side approaching infinity] and by 3 percent if it is unanticipated [see row 2, which is based on equation (11a) with t on the right-hand side equal to one]. Each of these responses is less than one-half of the long-run response of approximately 7.5 percent.

Clearly, the estimates indicate that cigarettes are addictive, that past and future changes significantly impact current consumption. This evidence is inconsistent with the hypothesis that cigarette consumers are myopic. Still, the estimates may not be fully consistent with rational addiction. The point estimates of the discount factor are implausibly low--the ratio of θ_F to θ_P in Table 3 ranges from .31 to .64. However, since future prices are not fully anticipated by consumers, estimates based on the assumption of perfect foresight overstate the variability of expected future prices. Due to an errors-in-variables bias, this leads to an understatement of the effect of future prices on current consumption. Therefore, uncertainty about future prices could explain the implausibly high discount rates implied by our estimates.

The future consumption coefficient also may be biased if the future price or the future excise tax rate is an endogenous variable that depends on current consumption. The direction of this bias is not obvious. On the one hand, states in which antismoking sentiment is widespread and current smoking is relatively low may raise their future excise tax rates in response to the antismoking campaign. On the other hand, states with high levels of current cigarette consumption may find that future excise tax hikes are attractive sources of revenue.[8]

Chaloupka (1989) provides further evidence in support of a rational model of cigarette addiction in a micro data set: the second National Health and Nutrition Examination Survey. Using measures of cigarette consumption in three adjacent periods, he fits demand functions similar to those in Table 3. He reports positive and significant future and past consumption coefficients and a short-run price elasticity (-.20) that is less than one-half of the long-run price elasticity of -.45.

VI. General Model

This section and the following section extend the theoretical results from Section II and the empirical results from the previous section by permitting more interactions between past and current consumption. The Becker-Murphy model differs from the model in Section II by allowing current utility to depend on a "stock" measure of past consumption, S, where S satisfies the law of motion

$$S_{t+1} = (1 - \delta)S_t + C_t \quad , \tag{19}$$

and δ measures the depreciation rate on the stock. Utility in each period depends on current cigarette consumption, C_t, and the current stock, S_t, as in

$$U_t = U(C_t, S_t) \ . \tag{20}$$

To save on notation, we ignore the consumption of other goods, Y, and the unobservable, e_t. These variables can be handled exactly as in Section II.

The first-order condition for consumption in period t is

$$U_C(C_t, S_t) + \sum_{\tau=1}^{\infty} \beta^{\tau}(1 - \delta)^{\tau-1} U_S(C_{t+\tau}, S_{t+\tau}) = \lambda P_t, \tag{21}$$

where U_C is the marginal utility of current consumption and U_S is the marginal utility of the stock variable, S ($U_S < 0$ given harmful addiction). The infinite series of future terms results from the effect of current consumption on the stocks in all future periods. These future terms are discounted at the rate $\beta(1 - \delta)$ since the future is discounted at the rate β and the stock depreciates at the rate δ. Using the first-order conditions for C_{t-1}, C_t, and C_{t+1}, the definition of the stock in equation (20), and assuming the utility function is quadratic, we get the second-order difference equation

$$C_t = \hat{\theta} C_{t-1} + \beta\hat{\theta} C_{t+1} + \hat{\theta}_0 + \hat{\theta}_1 P_t + \hat{\theta}_2 P_{t-1} + \beta\hat{\theta}_2 P_{t+1}, \tag{22}$$

where

$$\hat{\theta} = \frac{-U_{CC}(1 - \delta) + U_{CS}}{\Delta}$$

$$\hat{\theta}_0 = \frac{-\{\delta U_{CC}[1 - \beta(1-\delta)] + \delta\beta U_{CS}\}}{\Delta}$$

$$\hat{\theta}_1 = \frac{\lambda[1 + \beta(1-\delta)^2]}{\Delta}$$

$$\hat{\theta}_2 = \frac{-(1 - \delta)\lambda}{\Delta}$$

$$\Delta = [1 + \beta(1 - \delta)^2]U_{CC} + \beta U_{SS} + 2(1 - \delta)\beta U_{CS} < 0 \quad .$$

This equation is a generalization of equation (6), the equation estimated in the previous section. The major difference is that past and future prices enter now in addition to current price and past and future consumption. Nevertheless, the basic estimation strategy remains the same. Since the relevant unobservable variables are likely to be correlated over time, instrumental variables for C_{t-1} and C_{t+1} are required to obtain consistent estimates of the parameters. Tax variables and longer lags of the price variable are logical candidates for instruments. Additional empirical leverage is available from the condition that the discount factor, β, equals both the ratio of the coefficient of C_{t+1} to that of C_{t-1} and the ratio of the coefficient of P_{t+1} to that of P_{t-1}.

We can also derive an equation for myopic behavior that is similar to the myopic demand function in Section III except that now past price also enters on the right hand side. Once again, myopic behavior is nested within the rational behavior: myopic behavior implies zero coefficients in equation (22) for future price and future consumption.

VII. Empirical Results for the General Model

For the estimated version of (22), rational addiction implies positive coefficients on past and future consumption, positive coefficients on past and future prices, and a negative coefficient on current price. Positive coefficients on past and future prices may seem odd, given that past and future consumption are complementary with current consumption when behavior is addictive. However, controlling for past consumption eliminates the channel through which past prices affect current consumption. But the only way that past consumption stays fixed when past prices are higher would be for another force to offset higher past prices by raising the past stock of consumption capital. Since this higher value of the stock continues into the present period (reduced only by depreciation), current consumption must be higher when past prices are higher. This also explains why past and future prices were not in the estimating equation of the simple model. That model implies a depreciation rate of one, so that any larger past stock is eliminated entirely by depreciation.

The estimates of equation (22) in Table 6 use past, present, and future tax variables as instruments for past and future consumption. Column 1 uses state dummy variables for controls, while column 2 uses the state demographic variables described in previous sections. The signs on the two consumption variables and the three price variables conform with theoretical predictions. Past and future consumption positively impact on current consumption. Past and future prices also have positive effects when past and future consumption are held fixed. As in previous models, the income effects are positive, and the smuggling variables continue to be important determinants of state cigarette sales. The results for the demographic variables also are quite similar to those found in previous models: lower levels of education and higher divorce rates are associated with greater cigarette consumption, while the fraction of the population that is Mormon continues to have a negative effect. The state unemployment rate is essentially unrelated to smoking.

The estimates in the last three columns of Table 6 impose the restriction that future price and consumption effects equal the past effects multiplied by the discount factor. Column 3 imposes a discount factor of .95 and column 5 imposes one of .85. Similar results were obtained for all other discount factors that we tried between .7 and .95. Column 4 uses the state demographic controls and imposes a discount factor of .9. None of the restrictions imposed have a statistically significant effect on the sum of squared errors, implying that they are valid.

The different models have similar results that in most ways support rational addiction. The sum of the coefficients on past and future consumption are always less than unity, which indicates stable equilibrium. In all models, an exogenous force that raises either past or future consumption would also raise current consumption. As predicted, past and future prices have positive coefficients, and current price has a negative coefficient. The estimated roots of the difference equation for consumption (not shown) are always both significantly positive.

The elasticity estimates in Table 7 imply a greater long-run response to a permanent price reduction than to a temporary reduction or to a short-run reduction (compare row 1 to rows 2, 3, and 6). However, while almost all the elasticity estimates have the signs predicted by the addiction model, the effects of past prices on current consumption are not always significantly different from zero, and the effects of future prices are essentially zero in all models. Although these estimates do not fully support rational addiction, they are clearly inconsistent with myopic behavior. Myopia implies zero coefficients on future consumption and future price. This hypothesis is rejected strongly in all models. In models 1 and 2, where future effects are estimated independently of past effects, the F-statistics that both future effects are zero are 18.6 and 21.3, respectively, which reject the hypothesis that these effects are zero.

A time-separable demand function for cigarettes implies zero coefficients for all instrumented future and past effects of consumption and prices. It is obvious from looking at the regressions that this hypothesis too is decisively rejected. The F-statistics for models 1 and 2 are 615.7 and 799.2, respectively.

Even though our estimates indicate that the equilibrium aggregate amount of smoking is stable, unstable steady states may greatly affect the overall response of cigarette smoking to changes in cigarette prices. This conclusion is supported by the evidence that almost all the effect of higher prices on teenage smoking and more than half the effect on adult smokers are due to a decline in the number of smokers (Lewit, Coate, and Grossman 1981; Lewit and Coate 1982). The possible role of unstable steady states is inferred from the fact that the large decline in the number of smokers is not due entirely to heterogeneity in the amount smoked, whereby people who smoke only a few cigarettes per day stop smoking when cigarette prices increase. Data from the second National Health and Nutrition Examination Survey reveal that 60 percent of persons who had stopped smoking for less than one year smoked at least one pack of cigarettes per day during the last year in which they smoked. The same survey indicates that 68 percent of persons who had stopped smoking for one or more years smoked at least one pack a day during their period of maximum consumption.[9]

Even a modest increase in cigarette prices could induce smokers who happen to be near unstable steady states to cease (see the analysis in Becker and Murphy 1988). Those who had been trying to find an easy way to quit would have an added financial incentive to do so, and others near unstable steady states also might decide to quit. The existence of unstable steady states means that some people who smoke a lot will be the "marginal" smokers with respect to changes in cigarette prices and other variables.

VIII. Monopoly and Addiction

Both the demand for cigarettes and the organization of the cigarette industry have been studied frequently (on the latter, see, for example, Bain 1968; Sumner 1981; Appelbaum 1982; Geroski 1983; and Porter 1986). Yet neither type of study has highlighted the habitual-addictive side of smoking, even though cigarette smoking has long been recognized as a habit that is among the most difficult to break.

The cigarette industry in the U.S. is highly concentrated. Two companies (R.J. Reynolds and Philip Morris) account for about 70 percent of output, and the studies just cited conclude in general that cigarette companies have significant monopoly power. The analysis in previous sections shows that the habitual aspects of cigarette smoking significantly alter estimates of its response to changes in prices and other variables, and addiction affects optimal monopoly pricing and other policies.

To illustrate the relation between pricing and addiction, we consider monopoly pricing when there are only two periods. Quantities demanded in each period are given by the Cobb-Douglas functions[10]

$$(23) \qquad q_1 = a_1 p_1^{-\epsilon_1} p_2^{*-g\gamma}$$

$$(24) \qquad q_2 = a_2 p_2^{-\epsilon_2} q_1^{\gamma} ,$$

where ϵ_1, $\epsilon_2 > 0$, $0 < g < 1$, $0 \leq \gamma < 1$ with a reinforcing but stable habit and

p_2^* is the price expected in period 2 by consumers in period 1. Note that the price elasticities in equations (23) and (24) pertain to the individual firm, while the estimated price elasticities at sample means in Sections V and VII pertain to the market. Theoretically and empirically, the former elasticities are larger in absolute value than the latter (for example, Sumner 1981; Appelbaum 1982).

The present value of profits over the two periods is (with a zero interest rate)

$$\pi = p_1 q_1 + p_2 q_2 - c_1 q_1 - c_2 q_2 , \tag{25}$$

where c_1 and c_2 are the constant costs in each period inclusive of excise taxes. Substituting for q_1 and q_2 gives profits as a function of prices alone:

$$\pi = a_1 p_1^{1-\epsilon_1} p_2^{*-g\gamma} + a_2 a_1^{\gamma} p_2^{1-\epsilon_2} p_1^{-\epsilon_1 \gamma} p_2^{*-g\gamma^2}$$
$$- c_1 a_1 p_1^{-\epsilon_1} p_2^{*-g\gamma} - c_2 a_2 a_1^{\gamma} p_2^{-\epsilon_2} p_1^{-\epsilon_1 \gamma} p_2^{*-g\gamma^2} .$$

The firm chooses p_1 and p_2 to maximize π. The first-order condition for p_1 is

$$\frac{1 - \epsilon_1}{\epsilon_1} p_1 + c_1 = a_1^{\gamma-1} a_2 \gamma p_1^{\epsilon_1(1-\gamma)} p_2^{-\epsilon_2} p_2^{*\,g\gamma(1-\gamma)} (p_2 - c_2) . \tag{26}$$

We hold p_2^* constant when differentiating with respect to p_1 because rational expectations of p_2 are not affected by changes in p_1 with these demand functions. This reduces to the familiar condition that marginal revenue equals marginal cost $[p_1(1 - 1/\epsilon_1) = c_1]$ when either $\gamma = 0$ (no addictive effects of consumption) or when $p_2 = c_2$ (competitive pricing in the second period). However, marginal revenue is less than marginal cost in period 1 if $p_2 > c_2$ and if consumption is addictive. The reason is that profits in periods 2 are higher when q_1 is larger (p_1 is smaller) because an increase in q_1 raises q_2 (when $\gamma > 0$). As it were, a monopolist may lower price to get more consumers "hooked" on the addictive good. Note that, if the monopolist can engage in price discrimination, he may have an incentive to offer lower prices to persons who currently do not consume the good. This can explain why cigarette companies distributed free cigarettes on college campuses in the past. In effect college students were being offered a zero current price but a positive future price once they became addicted.

The right-hand side of equation (26) shows that the optimal marginal revenue in period 1 is lower relative to marginal cost when the good is more addictive (the larger is γ), demand in period 2 is stronger (the larger is a_2), demand in period 1 is weaker (the smaller is a_1), and when p_2 minus c_2 is bigger. With a sufficiently large positive effect on q_2 of a lower p_1, a monopolist might choose a p_1 that is less than c_1, or a p_1 that is in an inelastic region of demand ($\epsilon_1 < 1$).[11]

The choice of an optimal p_2 depends on whether the monopolist can precommit p_2 to consumers in period one. With precommitment, a decline in p_2 stimulates q_1 by lowering p_2^*. But without precommitment, actual changes in p_2 do not affect p_2^*, and hence do not affect q_1. Without precommitment, rational consumers simply anticipate that the monopolist chooses p_2 to maximize profits in period 2, given the level at that time of q_1. With rational expectations, $p_2^* = \hat{p}_2$ (the optimal p_2), and a monopolist who cannot precommit takes both q_1 and p_2^* as given when choosing p_2.

The first-order condition for p_2 to a monopolist who cannot precommit is

(27) $$a_2(1-\epsilon_2)p_2^{-\epsilon_2}q_1^{\gamma} = a_2c_2(-\epsilon_2)p_2^{-\epsilon_2-1}q_1^{\gamma}$$

or

(28) $$\frac{\epsilon_2-1}{\epsilon_2}\, p_2 = c_2 \ .$$

This is the usual condition that marginal revenue equals marginal cost. In particular, a monopolist who cannot precommit would never choose p_2 in the inelastic region of the demand curve in period 2 ($\epsilon_2 > 1$) because p_2 cannot influence q_1 without precommitment. Without going into details of the case where precommitment is possible, it should be clear that a precommitted p_2 would be below the p_2 given by equation (38) because a precommitted lower p_2 reduces p_2^*, and hence raises q_1 and profits in period 1 (assuming $p_1 > c_1$).

When p_2 is not precommitted, equations (37) and (38) can be substituted into the first-order condition for p_1 to get

(29) $$c_1 - a_2a_1^{\gamma-1}\ \gamma\epsilon_2^{-1}\ p_1^{\epsilon_1(1-\gamma)}\hat{p}_2^{1+g\gamma(1-\gamma)-\epsilon_2} = (1 - \frac{1}{\epsilon_1})p_1 \ .$$

If $1 < \epsilon_2 > 1 + g\gamma(1 - \gamma)$, which follows if $\epsilon_2 > 5/4$, then an increase in $\hat{p}_2$ raises p_1.[12]

This analysis is helpful in understanding the rise in cigarette prices in recent years. Much of the drop in demand for cigarettes since 1981 documented by Harris (1987) and others is due to greater information about health hazards, restrictions imposed on smoking in public places, and the banning of cigarette advertising on radio and television. Equation (29) shows that p_1 increases when demand falls by the same percentage in both periods (a_1 and a_2 fall by the same percentage); p_1 increases even more when future demand is expected to fall by a larger percentage than current demand. A rise in p_1 with c_1 fixed raises profit and profit margin (the difference between price and average cost) in period 1.

Several studies have commented about the apparent paradox that cigarette companies have been posting big profits while smoking is declining, and have documented the faster rise in cigarette prices than in apparent costs (Harris 1987; Dunkin, Oneal, and Kelly 1988). Indeed, according to Adler and Freedman (1990, p. 1), "...One of the great magic tricks of market economics...[is] how to force prices up and increase profits in an industry in which demand falls by tens of billions of cigarettes each year." Incorporation of the addictive aspects of smoking into the analysis resolves this paradox if cigarette companies have some monopoly power. Since p_1 increases, cigarette companies' profits rise in the short run precisely because of the decline in smoking. An event study of the common stock prices of cigarette companies could detect whether they fell relative to a risk-adjusted index of stock prices as the price of cigarettes rose during the 1980s.[13]

If consumers and producers know that an excise tax on cigarettes will be imposed next period, and if the cigarette industry were competitive with constant costs, present prices would not change and future prices would rise by the size of the tax. If the industry were oligopolistic but if cigarettes were not addictive, present prices still would not change, while future prices would rise by the same percentage as tax-inclusive future costs (with a constant elasticity of demand). Since price exceeds costs under monopoly, future monopolistic prices would rise by a greater amount than the excise tax.

The rise in cigarette prices does usually exceed the rise in cigarette taxes, which is evidence that the industry is not fully competitive (Sumner 1981).

Incorporation of the addictive aspects of smoking leads to a further test of whether the cigarette industry is fully competitive. If smokers are addicted, and if the industry is oligopolistic, an expected rise in future costs due to future taxes induces a rise in current prices [if ϵ_2, the price elasticity of demand for one of the oligopolists, in equation (28) exceeds 5/4], even though current demand (q_1) falls when future prices are expected to increase. A higher federal excise tax on cigarettes was widely expected to go into effect at the beginning of 1983. Cigarette prices increased sharply not only in 1983 but also prior to the tax increase during 1982. The price increase in 1982 has been taken as evidence that "the tax increase served as a focal point [or coordinating device] for an oligopolistic price increase" (Harris 1987, p. 101). That is possible, but an increase in 1982 would have occurred even if cigarette producers had no such coordinating problems. An oligopolistic producer of an addictive good would raise prices prior to an anticipated increase in the tax on his product.

FOOTNOTES

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[1]State-specific education and divorce measures were available for the Census of Population years of 1950, 1960, 1970, and 1980; and state-specific religion measures were available for the years 1952, 1971, and 1980. Values for other years were computed using state-specific exponential growth rates. Hence, differences in education, divorce, or religion are almost fully "explained" by the state and time variables. The algorithm also had to be applied to estimate the unemployment rate during the early years of the time series, and it is highly collinear with the set of state and time dummies.

[2]In the regressions in columns 3 and 4, the first observation on the dependent variable pertains to 1956 or to the second year in which both consumption and price are reported, and the last observation pertains to 1984. Fewer than 102 observations are lost because 65 of 1,581 cases have missing data in the regressions in columns 1 and 2, while 58 of 1,479 cases have missing data in the regressions in columns 3 and 4. Nine states have missing sales in 1955 and other years. Two of these states, Alaska and Hawaii, also

have missing prices. For these two states price is missing every year that sales are missing and in the first year in which sales are reported. Consequently, the number of cases with missing data falls by 7 rather than by 9 when one lag and lead of price are included in the regressions.

[3]Another bias arises because the dependent variable pertains to purchases rather than to consumption. If cigarettes can be stored, current purchases will rise in response to an increase in future or past price. This causes an underestimation of the absolute values of the future and past price coefficients. Thus, the negative and significant cross price effects in columns 3 and 4 may be even larger and more significant than they appear. To the extent that cigarettes spoil if they are stored for a period as long as a year, the bias just discussed is not important.

[4]The F tests are performed by estimating regressions with and without past and future price using 1,421 observations in each case.

[5]According to the solution of the second-order difference equation (6) or (22), consumption at any point in time depends on the current value and on <u>all</u> past and future values of a given exogenous variable [see equation (10)]. Clearly, not all these variables can be used to predict C_{t-1} and C_{t+1}. Therefore, both these variables are regressed on P_{t-1}, P_t, P_{t+1}, and X_t (a vector of the additional exogenous variables at time t). This procedure is followed because the set of exogenous variables should not vary among reduced form equations. Note that no past prices of C_{t-1} (P_{t-j}, $j > 1$) appear in the reduced form regression for C_{t-1}, and no future prices of C_{t+1} (P_{t+j}, $j > 1$) appear in the reduced form regression for C_{t+1}.

[6]The residuals from several of the models in Table 3 were examined for autocorrelation. The algorithm assumed a common time-series error structure

among states, and no autocorrelations for lag lengths greater than 10. The first ten autocorrelation coefficients were obtained and were used to compute a variance-covariance matrix of regression coefficients (var) of the form

$$\text{var} = (\hat{Z}'\hat{Z})^{-1}\,\hat{Z}'V\hat{Z}(\hat{Z}'\hat{Z})^{-1},$$

where V is the variance-covariance matrix of the disturbance term and

$$\hat{Z} = [\hat{Y}X_1] \ .$$

The last equation specifies a matrix of the predicted values of the endogenous variables ($\hat{Y}$) and exogenous variables (X_1) in the structural demand function for current consumption. Standard errors of regression coefficients based on this algorithm (available on request) were very similar to those that did not correct for autocorrelation. In most cases the corrected standard error was smaller than the corresponding uncorrected standard error. The same comment applies to the estimates in Table 6. The regression residuals also were examined for cross-sectional heteroscedasticity due to averaging over an unequal number of people in each state. This analysis suggested that there were no efficiency gains to weighting by the square root of the state population.

[7]The above computations assume that consumption this period, last period, and next period are approximately equal.

[8]Note that a Granger (1969) causality test of the relationship between cigarette consumption and the excise tax is not helpful in the context of our model. Suppose that the current tax rate was regressed on the lagged tax rate and on lagged consumption. Significant lagged consumption coefficients would

not necessarily indicate causality from consumption to the tax because lagged consumption should respond to the current tax given rational addiction.

[9]Frank Chaloupka kindly supplied us with the above estimates.

[10]These demand functions have constant price elasticities, while the demand functions estimated in Sections V and VII have constant slopes. We use the constant elasticity form in this section for analytical convenience and indicate how our conclusions would differ if the demand functions were linear.

[11]Of course, we assume that the demand function for current consumption has a constant price elasticity. In this context the constant value could be smaller than one. More generally, if the demand function did not have a constant elasticity, the monopolist might choose to operate in the inelastic segment of it.

[12]The term $\gamma(1 - \gamma)$ takes on a maximum value of 1/4 when γ equals 1/2. Since g is less than one, the condition in the text is sufficient but not necessary.

[13]Most of the results just obtained hold in certain cases with linear demand functions. In particular, price could rise in period 1 in response to parallel downward shifts in the demand functions in both periods. The results in this section suggest that it may not be entirely appropriate to treat price as an exogenous variable in fitting cigarette demand functions for reasons other than those mentioned in Section V and note 9. We reemphasize, however, that market demand functions are estimated in Sections V and VII, while the demand functions discussed in this section pertain to individual firms. Moreover, in the context of a non-addictive model, Porter (1986) reports little difference between cigarette market demand functions that treat price as exogenous and demand functions that treat price as endogenous.

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APPENDIX

I. Data

Cigarette sales were missing for nine states in the years specified below.

Alaska, 1955–1959

Hawaii, 1955–1960

California, 1955–1959

Colorado, 1955–1964

Maryland, 1955–1958

Missouri, 1955

North Carolina, 1955–1970

Oregon, 1955–1966

Virginia, 1955–1960

The price of cigarettes was missing for Alaska and Hawaii in each year in which sales were missing. In addition, price was not reported for the former state in 1960 and for the latter state in 1961.

The state excise tax on a pack of cigarettes is a weighted average of the tax rates in effect during the fiscal year, where the weights are the fraction of the year each rate was in effect. The Tobacco Tax Council gives the price of cigarettes as of November. The price used in our regressions in fiscal year t equals five-sixths of the price in November of year t-1 plus one-sixth of the price in November of year t, adjusted for changes in the state excise tax rate during the fiscal year. In particular, the state excise tax as of the date of the price was subtracted from the price; the average price exclusive of tax was computed from the preceding formula; and the average excise tax was added back to the price. The algorithm was modified in certain years in which price was reported in October. The price variable published by the Tobacco Tax Council (1986) excludes municipal excise taxes imposed on cigarettes by one or more municipalities in certain states. We created a state-specific average municipal excise tax rate [the sum of revenues from municipal cigarette excise taxes for the state as reported by the Tobacco Tax Council (various years) divided by state cigarettes sales in packs] and added this variable to the price. Note that the state excise tax rate defined in Table 1 and used as an instrumental variable for past and future consumption in Tables 3 and 6 is inclusive of the average municipal excise tax rate.

In every state except Hawaii and New Hampshire, the excise tax on cigarettes was a specific tax (fixed amount per pack) during our sample period. In Hawaii the tax was 40 percent of the wholesale price throughout the period. In New Hampshire the tax was 42 percent of retail price until fiscal 1976. Equivalent taxes per pack in these two states were computed by the Tobacco Tax Council.

Short-distance smuggling or casual bootlegging refers to out-of-state purchases by residents of a neighboring state with a higher excise tax. The short-distance importing and exporting incentive measures are used as separate regressors because consumption in an importing state (defined as sales plus imports) depends on the difference between the own state and the out-of-state price or tax. Consumption in an exporting state does not depend on this difference. Of course, both imports and exports respond to the tax difference. Long-distance smuggling or organized bootlegging refers to systematic attempts to ship cigarettes from North Carolina, Virginia, or Kentucky to other states. These cigarettes are sold at the retail prices prevailing in the relevant states without paying the excise tax, which is imposed at the wholesale level. Consumption in the importing state does not depend on the difference between that state's tax and the tax in North Carolina, Virginia, or Kentucky. Hence, long-distance importing and exporting incentives can be summarized by a single variable since imports summed over all states in a given year must equal exports summed over all states in that year. Given the definitions of the three smuggling variables in Table 1, their regression coefficients all should be negative.

Short distance casual smuggling effects are measured by two variables, one for imports and one for exports. The importing variable is

$$sdtimp_i = \sum_j k_{ij}(T_i - T_j),$$

where k_{ij} is the fraction of the population of state i (the higher tax state) living within 20 miles of state j (the lower tax state), and T_i and T_j are the cigarette excise tax rates in each state. The weights are computed from the 1970 Census of Population, and the summation is taken over neighboring states. The exporting variable is given by

$$sdtexp_i = \sum_j k_{ji}(T_i - T_j)(POP_j/POP_i),$$

where k_{ji} is the fraction of the higher taxed state's population living within 20 miles of the exporting state (state i) and POP_j denotes the population of state j. The reason that the population ratio is used in the export variable is that <u>total</u> exports from state i to state j should depend on the population of state j that lives near state i or POP_j multiplied by k_{ji}. Since the dependent variable in the regression model is state-specific per capita sales, dependent variable in the regression model is state-specific per capita sales, the population of state i enters the denominator. The tax differentials in the preceding formulas include or exclude municipal excise taxes depending on the border area at issue.

The construction of the long distance smuggling variable is based on several assumptions. It is assumed that Virginia and North Carolina share the long distance exporting to all states in the Northeast and Southeast as well as any state within 500 miles of either. All Western states within 1,000 miles of Kentucky are assumed to import from Kentucky. States more than 1,000 miles from Kentucky, Virginia, or North Carolina are assumed to do no long distance smuggling. The long distance smuggling variable based on these assumptions is given by

$$
\begin{aligned}
\ell dtax_i &= (T_i - T_{KY}) && \text{if importing from Kentucky} \\
&= z_{NC}(T_i - T_{NC}) + z_{VA}(T_i - T_{VA}) && \text{if importing from N.C. and Va.} \\
&= \sum_j (T_{KY} - T_j)(POP_j/POP_{KY}) && \text{for Kentucky} \\
&= z_i[\sum_j (T_i - T_j)(POP_j/POP_i)] && \text{for i = N.C., Va.}
\end{aligned}
$$

The weights used for states that import from North Carolina and Virginia are the shares of value added in the production of cigarettes in these two states combined accounted for by each one. That is, z_{NC} = value added in N.C./(value added in N.C. + value added in Va.). Note that total imports from Kentucky, North Carolina, or Virginia to state i depend on the population of i which cancels when imports are expressed on a per capita basis. If state i's excise tax was lower than the exporting state's excise tax, which occurred in a few states prior to fiscal 1967, the tax difference was set equal to zero.

State-specific money per capita income in fiscal year t is a simple average of money per capita income in calendar years t-1 and t. The consumer price index in fiscal year t, which is not state-specific, is defined in a similar manner. Per capita income by state was taken from the Bureau of Economic Analysis (various years). Unemployment rates by state were obtained from the Bureau of Labor Statistics (various years). The state-specific education and divorce measures were available for the Census of Population years of 1950, 1960, 1970, and 1980 (Bureau of the Census 1983). Values for other years were computed using state-specific exponential growth trends. These values were adjusted so that a weighted average of the variable at issue for an intercensal year was equal to the observed national rate as reported by the Bureau of the Census (various years). For example, let x_{jt} be the percentage of the population 25 years of age and older with at least a high school education in the j^{th} state in year t based on the exponential growth trend. Define x_t as

$$x_t = \sum_j k_{jt} x_{jt},$$

where k_{jt} is the fraction of the U.S. population aged 25 and older residing in the j^{th} state in year t. Finally, let y_t be the observed percentage of the U.S. population aged 25 and older with at least a high school education in year t. Then the adjusted estimate for the j^{th} state (y_{jt}) is given by

$$y_{jt} = (y_t/x_t)x_{jt}.$$

In the case of the divorce measure (the fraction of women aged 25 through 34 who are divorced), the weight (k_{jt}) in the first formula pertains to the fraction of women aged 25 through 34 in the U.S. who reside in the j^{th} state. The same algorithm also was employed to estimate unemployment rates that were missing in certain states during the early years of the time series.

The religion measures were reported for the years 1952, 1971, and 1980 from surveys conducted by the National Council of the Churches of Christ and the Glenmary Research Center (Whitman and Trimble 1956; Johnson, Picard, and Quinn 1974; Quinn et al. 1982). Values for other years were computed using the algorithm employed for education and divorce. Since national measures were not available for years other than those in which the three surveys were conducted, a weighted average of the state-specific estimated values could not be constrained to equal a national figure.

II. Instruments for Two-Stage Least Squares Models

The five sets of instruments in the models in Table 3 are as follows. All models have as instruments year dummy variables, the smuggling measures, income, current price, and one period lead and lag values of price. Each model also has as instruments either state dummy variables or the socioeconomic variables (education, divorce, religion, and unemployment), depending on which of these sets of variables was included in the structural equation in question. Model 1 in Table 3 has no other instruments. Model 2 includes the current tax and the one period lag value of the tax. Model 3 and 5 include the current tax and the one period lead and lag values of the price and tax. Model 4 adds the two period lag values of the tax and price to the additional variables used in models 3 and 5. The potential number of cases in a model with one lag and one lead of price as instruments is 1,479 (the 29 years from 1956 through 1984 times 50 states and the District of Columbia). The corresponding figure in a model with two lags and one lead of price as instruments is 1,428 (the 28 years from 1957 through 1984 times 50 states and the District of Columbia). Missing data (see note 2) reduce the actual number of cases to 1,414 in the first model and to 1,370 in the second model.

The common set of instruments used in all five models in Table 6 is specified above. Models 1 and 2 also include the current value of the state excise tax and the one period lead and lag values of the tax. Models 3, 4, and 5 exclude the last two regressors but constrain the coefficients on past and future price and on past and future consumption.

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Table 1

Definitions, Means, and Standard Deviations of Variables
(s.d. = standard deviation)

C_t	Per capita cigarette consumption in packs in fiscal year t, as derived from state tax-paid sales (mean = 124.800, s.d. = 31.958)
P_t	Average retail cigarette price per pack in January of fiscal year t in 1967 cents (mean = 29.600, s.d. = 3.300)
income	Per capita income on a fiscal year basis, in hundreds of 1967 dollars (mean = 29.303, s.d. = 8.539)
ℓdtax	Index which measures the incentives to smuggle cigarettes long distance from Kentucky, Virginia, or North Carolina. The index is positively related to the difference between the state's excise tax and the excise taxes of the exporting states. See panel B for more information on this variable and the following smuggling variables (mean = -.400, s.d. = 17.800)
sdtexp	Index which measures short distance (export) smuggling incentives. The index is a weighted average of differences between the exporting state's excise tax and excise taxes of neighboring states, with weights based on border populations (mean = -.800, s.d. = 1.800)
sdtimp	Index which measures short distance (import) smuggling incentives in a state. Similar to sdtexp (mean = .500, s.d. = .800)
hs	Percentage of state population ages 25 and over with at least a high school education (mean = 52.880, s.d. = 14.850)
divorce	Percentage of state female population aged 25-34 that are divorced (mean = 4.960, s.d. = 14.850)
unemp	State unemployment rate as a percentage (mean = 5.410, s.d. = 2.300)
mormon	Percentage of state population that are Mormon (mean = 2.696, s.d. = 10.010)
sobapt	Percentage of state population that are Southern Baptist (mean = 6.330, s.d. = 9.120)
catholic	Percentage of state population that are Catholic (mean = 18.940, s.d. = 13.410)
tax	Sum of state and local excise taxes on cigarettes in 1967 cents per pack (mean = 6.400, s.d. = 2.900)

Table 2

Ordinary Least Squares Regressions, Dependent Variable = C_t
(Absolute t-statistics in parentheses, intercepts not shown)

	(1)*	(2)**	(3)*	(4)**
P_{t-1}			-2.073 (7.89)	-1.949 (4.30)
P_t	-3.018 (15.40)	-3.216 (13.39)	-.626 (1.72)	-.685 (1.09)
P_{t+1}			-.834 (3.05)	-.809 (1.72)
Y_t	1.530 (8.88)	1.610 (13.62)	1.620 (9.14)	1.660 (13.50)
ℓdtax	-.366 (7.37)	-.337 (9.56)	-.304 (5.99)	-.314 (8.63)
sdtimp	-1.847 (3.60)	1.598 (2.60)	-2.042 (4.03)	1.115 (1.80)
sdtexp	-6.096 (18.00)	-8.847 (33.80)	-5.964 (17.20)	-8.843 (33.10)
hs		-.335 (2.91)		-.388 (3.25)
divorce		5.97 (14.30)		6.17 (14.20)
mormon		-.443 (8.53)		-.441 (8.25)
catholic		.370 (8.07)		.383 (8.05)
sobapt		.116 (1.29)		.118 (1.26)
unemp		.497 (1.76)		.388 (1.32)
R-squared	.909	.724	.917	.730
N	1,516	1,516	1,421	1,421

* Regressors include state and year dummy variables.

** Regressors include year dummy variables.

Table 3

Two-Stage Least Squares Regressions,
Dependent Variable = C_t (Asymptotic t-statistics in parentheses)*

	(1)**	(2)**	(3)**	(4)**	(5)***
$\hat{C}_{t-1}$	.424	.375	.443	.480	.453
	(9.06)	(9.25)	(11.80)	(14.50)	(8.90)
$\hat{C}_{t+1}$	.133	.239	.172	.229	.205
	(2.42)	(5.11)	(3.87)	(5.94)	(3.37)
P_t	-1.392	-1.229	-1.230	-.981	-1.141
	(8.96)	(9.16)	(9.17)	(8.44)	(7.29)
Y_t	.831	.753	.741	.607	.595
	(7.31)	(7.42)	(7.31)	(6.72)	(7.39)
ℓdtax	-.187	-.147	-.161	-.125	-.110
	(5.40)	(4.78)	(5.26)	(4.46)	(5.32)
sdtimp	-1.342	-1.202	-1.248	-1.075	-.006
	(4.78)	(4.65)	(4.83)	(4.57)	(.21)
sdtexp	-3.202	-2.868	-2.897	-2.404	-3.187
	(11.30)	(11.90)	(12.00)	(11.60)	(8.36)
hs					-.162
					(3.35)
divorce					2.08
					(6.82)
mormon					-.145
					(5.21)
catholic					.126
					(5.33)
sobapt					.043
					(1.20)
unemp					.046
					(.39)
R-squared	.975	.979	.979	.983	.949
N	1,414	1,414	1,414	1,370	1,414

* A hat over a variable means it is endogenous. Intercepts not shown.
** Regressors include state and year dummy variables.
*** Regressors include year dummy variables.

Table 4

Roots of Difference Equation
(approximate standard errors in parentheses)

	ϕ_1	ϕ_2
Model 1	.141 (.062)	2.218 (.224)
Model 2	.265 (.056)	2.405 (.254)
Model 3	.188 (.052)	2.069 (.162)
Model 4	.263 (.049)	1.822 (.114)
Model 5	.229 (.074)	1.976 (.201)

Table 5

Price Elasticities for Two-Stage Least Squares Models
(approximate t-statistics in parentheses)

	(1)	(2)	(3)	(4)	(5)
Long run	-.743	-.753	-.757	-.799	-.791
	(13.06)	(12.43)	(12.43)	(10.67)	(11.81)
Own price:					
anticipated	-.374	-.363	-.350	-.310	-.341
	(10.73)	(11.13)	(10.86)	(9.87)	(9.27)
unanticipated	-.351	-.323	-.318	-.266	-.301
	(9.97)	(10.09)	(10.10)	(9.20)	(8.28)
Future price:					
unanticipated	-.050	-.086	-.060	-.070	-.069
	(2.37)	(4.90)	(3.70)	(5.14)	(3.21)
Past price:					
unanticipated	-.158	-.134	-.154	-.146	-.153
	(8.99)	(8.01)	(9.80)	(9.43)	(8.23)
Short run	-.408	-.440	-.391	-.360	-.391
	(9.34)	(9.51)	(9.69)	(8.80)	(7.66)

Table 6

General Two-Stage Least Squares Regressions,
Dependent Variable = C_t (Asymptotic t-statistics in parentheses)

	(6)**	(7)***	(8)**	(9)***	(10)**
$\hat{C}_{t-1}$	.495	.505	.417	.470	.441
	(8.03)	(7.66)	(14.79)	(22.60)	(14.93)
$\hat{C}_{t+1}$	.294	.350	.396	.423	.375
	(3.99)	(4.59)	(14.79)	(22.60)	(14.93)
P_{t-1}	.613	.758	.662	.890	.694
	(2.83)	(3.57)	(4.01)	(6.74)	(4.00)
P_t	-1.685	-1.906	-1.697	-1.931	-1.687
	(10.20)	(11.30)	(10.40)	(12.30)	(10.37)
P_{t+1}	.569	.772	.628	.801	.590
	(2.53)	(3.58)	(4.01)	(6.74)	(4.00)
Y_t	.502	.274	.480	.215	.474
	(4.79)	(3.56)	(4.53)	(3.05)	(4.50)
ℓdtax	-.100	-.053	-.072	-.040	-.076
	(3.06)	(3.19)	(2.66)	(2.69)	(2.85)
sdtimp	-.976	-.302	-.877	-.337	-.888
	(4.30)	(1.74)	(4.07)	(2.11)	(4.14)
sdtexp	-1.970	-1.491	-1.795	-1.137	-1.798
	(6.06)	(3.82)	(5.71)	(3.28)	(5.78)
hs		-.091		-.074	
		(2.69)		(2.43)	
divorce		.884		.650	
		(3.06)		(2.47)	
mormon		-.057		-.040	
		(2.44)		(1.87)	
catholic		.045		.030	
		(2.17)		(1.58)	
sobapt		.011		.002	
		(.44)		(.10)	
unemp		-.037		-.025	
		(.46)		(.36)	
R-squared	.986	.978	.986	.981	.986
N = 1,414 all models					

* A hat over a variable means it is endogenous. Intercepts not shown.
** Regressors include state and year dummy variables.
*** Regressors include year dummy variables.

Table 7

Price Elasticities for General Two-Stage Least Squares Models
(approximate t-statistics in parentheses)

	(6)	(7)	(8)	(9)	(10)
Long run	-.565	-.612	-.515	-.533	-.517
	(4.30)	(4.87)	(3.29)	(3.02)	(3.28)
Own price:					
anticipated	-.412	-.462	-.420	-.468	-.419
	(11.62)	(12.37)	(11.43)	(12.58)	(11.44)
unanticipated	-.422	-.480	-.409	-.461	-.406
	(10.45)	(11.39)	(11.61)	(13.25)	(11.58)
Future price:					
unanticipated	.013	.020	-.016	-.007	-.016
	(0.44)	(0.77)	(0.61)	(0.38)	(0.62)
Past price:					
unanticipated	-.077	-.081	-.017	-.008	-.019
	(1.98)	(2.09)	(0.61)	(0.38)	(0.62)
	-.386	-.410	-.465	-.496	-.460
	(5.25)	(4.94)	(5.40)	(5.50)	(5.77)
Short run	-.402	-.444	-.442	-.478	-.437
	(9.02)	(9.75)	(7.71)	(9.11)	(8.24)