An Empirical Analysis of Cigarette Addiction

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To test a model of rational addiction, we examine whether lower past and future prices for cigarettes raise current cigarette consumption. The empirical results tend to support the implication of addictive behavior that cross price effects are negative and that long-run responses exceed short-run responses. Since the long-run price elasticity of demand is almost twice as large as the short-run price elasticity, the long-run increase in tax revenue from an increase in the federal excise tax on cigarettes is considerably smaller than the short-run increase. (*JEL* D11, D12, I10).

In Becker and Murphy (1988), a theoretical model was developed in which utility-maximizing consumers may become "addicted" to the consumption of a product, and the key empirical predictions were outlined. In the Becker-Murphy framework consumers are rational or farsighted in the sense that they anticipate the expected future consequences of their current actions. 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 1955–1985. The empirical results indicate that smoking is addictive.

The Becker-Murphy model follows Harl E. Ryder, Jr., and Geoffrey M. Heal (1973), George J. Stigler and Becker (1977), Marcel Boyer (1978, 1983), Frans Spinnewyn (1981), and Lawrence R. Iannaccone (1986) by considering the interaction of past and current consumption in a model with utility-maximizing consumers. 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.

This paper tests the model of rational addiction by considering 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 tend to support the implication of addictive behavior that cross price effects are negative and that long-run responses exceed short-run responses.

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

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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 0.6 percent and decreases 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. We are not able to test other implications of the Becker-Murphy model such as abrupt quitting behavior by cold turkey.

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 imply that past prices have negative effects on current consumption, but that they imply that there is 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, while they tend to support the model of rational addiction. However, some results cannot readily be explained by rational addiction.

The cigarette industry raised the price of cigarettes in 1982 as well as in 1983 when the federal excise tax on cigarettes increased. The industry also raised cigarette prices throughout the 1980's presumably 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 effect of addictive behavior on aggregate cigarette consumption, because a monopolist will take account of the effect of current price on the demand for future consumption.

Our results are relevant to government regulation of the cigarette industry. Since the first Surgeon General's Report on Smoking and Health in 1964, the federal government and state governments have carried out policies to increase public knowledge about the harmful effects of smoking, to restrict advertising by cigarette manufacturers, and to create no-smoking areas in public places and in the workplace. These policies will induce monopolistic producers to raise current prices because the decline in future demand that they cause reduces the gains from maintaining a lower price to stimulate future consumption. This indirect effect of the antismoking campaign in the form of higher prices has not been taken into account in evaluations of the campaign (e.g., Kenneth E. Warner, 1986).

Our results also are relevant in estimating the potential revenue yield of an increase in the federal excise tax rate on cigarettes to help finance national health-care reform or to reduce the federal deficit. Given the addictive nature of smoking, consumption of cigarettes is positively related to past consumption. For example, a price hike in 1993 due to an increase in the federal excise tax rate would reduce consumption in 1993, which would cause consumption in 1994 and in all future years to fall. Since we find that the long-run price elasticity is almost twice as large as the short-run price elasticity, the long-run increase in tax revenue would be considerably smaller than the short-run increase.

I. The Basic Model

Most empirical analyses of consumption deal with single-period models or 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 in order 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

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

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 to 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

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

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 and all other types of uncertainty. 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

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

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

Equation (3a) is the usual condition that the marginal utility of other 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 also are valid in the case of beneficial addiction ($U_2 > 0$).

Since with perfect certainty 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. By solving the first-order condition for Y_t and substituting the result into the first-order condition for C_t, 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}:

$$(4) \qquad C_t = \theta C_{t-1} + \beta\theta C_{t+1} + \theta_1 P_t + \theta_2 e_t + \theta_3 e_{t+1}$$

where

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

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

$$\theta_3 = \frac{-\beta(u_{yy}u_{2e} - u_{2y}u_{2e})}{\left(u_{11}u_{yy} - u_{1y}^2\right) + \beta\left(u_{22}u_{yy} - u_{2y}^2\right)}$$

where lowercase letters denote the coefficients of the quadratic utility function, and the intercept is suppressed.

Since θ_1 is negative by concavity of U, equation (4) implies that increases in the current price decrease current consumption, C_t, when the marginal utility of wealth, past consumption, and future consumption are fixed.[1] 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

$$(5)\quad \theta = \frac{-(u_{12}u_{yy} - u_{1y}u_{2y})}{(u_{11}u_{yy} - u_{1y}^2) + \beta(u_{22}u_{yy} - u_{2y}^2)} > 0.$$

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 (4) 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 (4) would lead to inconsistent estimates of the parameters of interest. The unobserved 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 (4). Positive serial correlation in the unobserved effects incorrectly implies that past and future consumption positively affect current consumption, even when the true value of θ is zero.

Fortunately, the specification in equation (4) suggests a way to solve this endogeneity problem, since it implies that current consumption is independent of past and future prices when C_{t-1} and C_{t+1} are held fixed. That is, 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 (4), 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 to derive cross price elasticities between cigarette consumption levels at different points in time that test how important addiction is to aggregate cigarette consumption. It is intuitively clear from equation (4) 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 period $t-1$, 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 (4). The solution and the various price effects in the model are contained in Appendix A. The solution results in an equation in which consumption in period t depends on prices in all periods. This equation determines the sign of the

[1]Price effects that do not hold past and future consumption constant are considered later in the paper.

effects of changes in the price of cigarettes in period τ on cigarette consumption in period t. These effects are temporary in nature since prices in other periods are held constant. The temporary own or current price effect must be negative. The sign of the cross price effect depends entirely on the sign of the coefficient of past consumption (θ) in equation (4). The goods in any two consecutive periods are complements (i.e., negative cross price effects) if and only if θ is positive.

Since an increase in past consumption increases current consumption if a good is addictive, fully anticipated price effects must exceed completely unanticipated price effects in absolute value. The latter describes a price change in period t that is not anticipated until that period, so that past consumption is not affected. The former describes a price change in period t that is anticipated as of the planning date, so that past consumption is affected.

In addition to the own price effects, cross price effects, and the difference between anticipated and unanticipated price effects, there are important differences between long- and short-run responses to permanent price changes in the context of addiction. The short-run price effect describes the response to a change in price in period t and all future periods that is not anticipated until period t. The long-run price effect pertains to a price change in *all* periods. Since C_{t-1} remains the same if a price change is not anticipated until period t, the long-run price effect must exceed the short-run price effect. In addition, the long-run price effect must exceed the fully anticipated temporary own price effect.

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 prices.

II. 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 addiction and habit formation (see e.g., Robert A. Pollak, 1970, 1976; Menahem E. 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 a first-order condition that does not contain the future effect βU_2.

Differences between myopic and rational behavior are highlighted by solving the myopic first-order condition for C_t to get the myopic equivalent of equation (4). The major difference between equation (4) 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

TABLE 1—DEFINITIONS, MEANS, AND STANDARD DEVIATIONS (SD) OF VARIABLES

Variable	Definition (mean, SD)
C_t	Per capita cigarette consumption in packs in fiscal year t, as derived from state tax-paid sales (mean = 126.171, SD = 31.794)
P_t	Average retail cigarette price per pack in January of fiscal year t in 1967 cents (mean = 29.812, SD = 3.184)
income	Per capita income on a fiscal-year basis, in hundreds of 1967 dollars (mean = 31.439, SD = 8.092)
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 (mean = 0.160, SD = 15.572)
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 = −0.828, SD = 1.847)
sdtimp	Index which measures short-distance (import) smuggling incentives in a state. Similar to sdtexp (mean = 0.494, SD = 0.792)
tax	Sum of state and local excise taxes on cigarettes in 1967 cents per pack (mean = 6.582, SD = 2.651)

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.

III. 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 per capita cigarette consumption in these data reflects the behavior of a representative consumer. To be sure, we cannot study the decision to start or quit smoking, given the aggregate nature of the data. But Becker and Murphy's (1988) treatment of unstable steady states indicates that the same forces that govern consumption of an addictive good, given participation, also govern these decisions. For example, the quit probability in period t is positively related to current price and negatively related to consumption in periods $t-1$ and $t+1$. However, it depends on where a person starts from and the magnitude of these changes in price and consumption.

Table 1 contains definitions, means, and standard deviations of the primary variables in the data set (see Appendix B for a detailed discussion of the data). 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 Badi H. Baltagi and Dan Levin (1986). None of them contains the refined measures of incentives for short- and long-distance smuggling of cigarettes across state lines that we employ (see below) or considers 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 1,517. 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 for 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 fixed state effects (dichotomous variables for each state except one).

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 variables use 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 United States, based on value added and had the three lowest excise tax rates in the country starting in fiscal 1967.

The demand function developed in Section I of this paper is one that holds the marginal utility of wealth constant. In a model with perfect foresight, the marginal utility of wealth is fixed over time but varies among individuals and therefore among states. Thus, the state dummies capture this variation. The coefficients of the time dummies reflect in part the effects of unanticipated growth in wealth, which cause the marginal utility of wealth to change over time. We assume that deviations in real per capita income around state- and time-specific means follow a random walk, or more generally a first-order autoregressive process. In these cases unanticipated state-specific changes in real wealth over time, or deviations in real wealth from state- and time-specific means, are determined fully by deviations in real per capita income from state- and time-specific means. Put differently, with the state and time dummies held constant, the coefficient of real per capita income reflects forces associated with state-specific changes in the marginal utility of wealth over time.[2]

IV. Empirical Results

Our estimation strategy is to begin with the myopic model. We then test the myopic model by testing whether future prices are significant predictors of current consumption as they would be in the rational-addiction model, but not under the myopic framework. Since consumers base their current consumption decisions on expected future price under the rational-addiction framework, the actual future price suffers from the classical errors-in-variable problem in which the measurement error is uncorrelated with expected future price and all other variables in the equation. Under the null hypothesis of the myopic framework, our coefficient estimate is still unbiased and represents a valid test of the myopic model.

The first three columns of Table 2 contain two-stage least-squares (2SLS) estimates of myopic models of addiction, while the last column contains an ordinary least-squares (OLS) estimate. Past consumption is treated as an endogenous variable in the first three columns because of the high likelihood that the unobserved variables that affect current utility (e_t) are serially correlated.[3] The instruments used in column (i) consist of past price (P_{t-1}) plus the other explanatory variables in the model. Column (ii) adds the current and one-period lag values of the state cigarette tax to the instruments, and column (iii) further adds two additional lags of the price and tax variables. State excise taxes are used as instruments in some of the models for reasons indicated below.[4] The table also contains F ratios resulting from De-Min Wu's (1973) test of the hypothesis that OLS estimates are consistent. Since this hypothesis always is rejected, we stress the 2SLS results.

According to the parameter estimates of the myopic model presented in Table 2, cigarette smoking is inversely related to cur-

[2]The coefficient of current price (θ_1) in equation (4) depends on the parameters of the utility function, the discount factor, and the marginal utility of wealth. Strictly speaking, price should be interacted with any variable that determines the marginal utility of wealth. Such an equation is not tractable from the standpoint of estimation due to its large set of regressors and potential for creating severe problems of multicollinearity. Our procedure, which captures variations in the marginal utility of wealth but not interactions between the determinants of this variable and price, may be viewed as a linear approximation to the true model. Essentially, we estimate the price coefficient associated with the marginal utility of wealth evaluated at its mean value. Technically, if the marginal utility of C_t does not depend on Y_t, the only coefficient in equation (4) that depends on the marginal utility of wealth is the coefficient of current price. That coefficient equals $\lambda\alpha$, where α equals $1/(u_{11}+\beta u_{22})$. Suppressing subscripts and variables other than current price and the constant, this equation can be written as

$$C=\theta_0+\alpha\lambda P.$$

As an identity,

$$\lambda P=\bar{\lambda}\bar{P}+v\bar{\lambda}+w\bar{P}+vw$$

where a bar over a variable denotes a mean, v equals the deviation of P from its mean, and w equals the deviation of λ from its mean. If vw approaches zero,

$$C=\theta_0+\alpha\bar{\lambda}\bar{P}+\alpha\bar{\lambda}P+\alpha\bar{P}\lambda.$$

[3]In the rational-addiction model, C_{t-1} depends on e_t through the optimizing behavior implied by the first-order conditions. Therefore, past consumption must be treated as an endogenous variable in estimating this model even if e_t is not serially correlated.

[4]Since the regressions in Table 2 are reestimated after adding future price, models (i) and (ii) contain 1,415 (1,517 − 102) observations. Fewer than 51 observations are lost when the second lag of price is introduced, due to the pattern of missing price data. In particular, seven states have missing cigarette sales but known prices in certain years.

rent price and positively related to income.[5] The highly significant effects of the smuggling variables (ℓdtax, sdimp, and sdexp) indicate the importance of interstate smuggling of cigarettes. The positive and significant past-consumption coefficient is consistent with the hypothesis that cigarette smoking is an addictive behavior. The parameter estimates in the table are quite stable across the three alternative sets of instruments for past consumption.

When the one-period lead of price is added to the 2SLS models in Table 2, its coefficient is negative and significant at all conventional levels. The absolute t ratio associated with the coefficient of this variable is 5.06 in model (i), 5.54 in model (ii), and 6.45 in model (iii). These results suggest that decisions about current consumption depend on future price. They are inconsistent with a myopic model of addiction, but consistent with a rational model of this behavior in which a reduction in expected future price raises expected future consumption, which in turn raises current consumption. While these tests soundly reject the myopic model, they do not provide definitive evidence in support of the rational-addiction model outlined above because they do not impose the constraint that the future-price effect works solely through future consumption. Nevertheless, they suggest that consumers do consider future prices in their current consumption decisions and hence that it is worth trying to obtain structural estimates of rational-addiction demand functions.

Two strategies can be pursued in fitting the rational-addiction model. One is to use the actual future price as an instrument for future consumption. The problem with this strategy is that the forecast error in future price creates a downward bias in the coefficient of future consumption. The second strategy is to restrict the set of instruments to lagged values of prices and taxes. This is a common general strategy in estimating the effects of expected future variables.

There are two problems with the second strategy. First, consumers have a good deal of information concerning the state-specific future price of cigarettes, because this price depends to a large extent on the future state excise tax rate on cigarettes. Excise tax hikes are announced in advance and receive a good deal of publicity as a result of delays in the legislative process. Moreover, most states raise their excise tax rates in response to revenue shortfalls (see e.g., Eugene E. Lewit, 1982). Hence, it is plausible that tax hikes are anticipated even before the corresponding bills are introduced in state legislatures. Phrased differently, if consumers have information concerning future prices and taxes, then one is losing valuable information by discarding these variables as instruments.

Second, past prices and taxes simply are not good predictors of the future price. Consider a regression of the future price on all the exogenous variables in the demand function, the one-period lag of the price, the one-period lag of the tax, and the current tax. At the 1-percent level, the last three variables are not significant as a set in

[5]The residuals from several of the models in Table 2 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

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

where $\mathbf{V}$ is the variance-covariance matrix of the disturbance term and

$$\hat{\mathbf{Z}} = [\hat{\mathbf{Y}}\mathbf{X}_1].$$

The last equation specifies a matrix of the predicted values of the endogenous variables ($\hat{\mathbf{Y}}$) and exogenous variables ($\mathbf{X}_1$) in the structural demand function for current consumption. Standard errors of regression coefficients based on this algorithm (available from the authors upon 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 Tables 3 and 5. 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.

TABLE 2—ESTIMATES OF MYOPIC MODELS OF ADDICTION, DEPENDENT VARIABLE = C_t (ASYMPTOTIC t STATISTICS IN PARENTHESES)

Independent variable	2SLS (i)	2SLS (ii)	2SLS (iii)	OLS (iv)
C_{t-1}	0.478	0.502	0.602	0.755
	(12.07)	(14.68)	(21.43)	(64.84)
P_t	−1.603	−1.538	−1.269	−0.860
	(10.12)	(10.48)	(9.74)	(8.33)
Y_t	0.942	0.903	0.741	0.493
	(7.61)	(7.71)	(6.96)	(5.44)
ℓdtax	−0.240	−0.233	0.212	−0.160
	(7.33)	(7.40)	(7.22)	(6.17)
sdtimp	−1.541	−1.514	−1.372	−1.228
	(5.04)	(5.09)	(4.97)	(4.84)
sdtexp	−3.659	−3.544	−3.059	−2.328
	(13.24)	(13.88)	(13.71)	(13.15)
R^2:	0.969	0.970	0.976	0.979
Wu F ratio:	84.76	94.42	41.61	—
N:	1,415	1,415	1,371	1,415

Notes: Intercepts are not shown. Regressors include state and year dummy variables. Columns (i)–(iii) give two-stage least squares (2SLS) estimates with C_{t-1} treated as endogenous. Column (iv) gives an ordinary least-squares (OLS) estimate. The instruments in column (i) consist of the one-period lag of price plus the other explanatory variables in the model. Column (ii) adds the current and one-period lag values of the state cigarette tax to the instruments, and column (iii) further adds two additional lags of the price and tax variables. The Wu F ratios pertain to tests of the hypothesis that the OLS models corresponding to the first three columns are consistent. They all are significant at the 1-percent level.

the regression ($F = 3.0$, compared to a critical F ratio of 3.8). Addition of a second lag of the price and the tax does not improve matters because the F statistic falls to 2.0, compared to a critical F of 3.0. Even these computed F ratios are, however, biased upward because the real issue is whether past prices and taxes are significant predictors of future price net of their contribution to the prediction of past consumption. When predicted past consumption is added to the regressions just described, the F statistics fall to 0.1 and 1.5, respectively.

Charles R. Nelson and Richard Startz (1990) have shown that the use of a poor instrument (an instrument that explains little of the variation in an endogenous right-hand-side variable) can produce a large bias in the estimated coefficient of the endogenous variable relative to its standard error. They state (p. S139), "In the context of estimating stochastic Euler equations, we would particularly caution against the use of lagged changes in consumption or lagged stock returns as instruments for current values...." In our case, this implies even more caution against the use of past prices as instruments for future consumption. Therefore, our preferred estimation strategy uses future price directly as a predictor of future consumption; but we present results both for this strategy and for the one that restricts the instruments to past prices and taxes.

Table 3 tests the rational-addiction model directly by estimating equation (4) with past

TABLE 3—ESTIMATES OF RATIONAL MODELS OF ADDICTION, DEPENDENT VARIABLE = C_t (ASYMPTOTIC t STATISTICS IN PARENTHESES)

Independent variable	2SLS (i)	(ii)	(iii)	(iv)	OLS (v)
C_{t-1}	0.418	0.373	0.443	0.481	0.485
	(8.88)	(9.18)	(11.72)	(14.58)	(36.92)
C_{t+1}	0.135	0.236	0.169	0.228	0.423
	(2.45)	(5.04)	(3.79)	(5.87)	(28.61)
P_t	−1.388	−1.230	−1.227	−0.971	−0.412
	(8.94)	(9.11)	(9.11)	(8.36)	(4.98)
Y_t	0.837	0.761	0.746	0.608	0.302
	(7.34)	(7.44)	(7.31)	(6.72)	(4.21)
ℓdtax	−0.188	−0.150	−0.164	−0.127	−0.022
	(5.42)	(4.82)	(5.30)	(4.50)	(1.05)
sdtimp	−1.358	−1.222	−1.266	−1.090	−0.748
	(4.82)	(4.70)	(4.88)	(4.63)	(3.73)
sdtexp	−3.218	−2.892	−2.914	−2.401	−1.347
	(11.37)	(11.84)	(11.96)	(11.58)	(9.39)
R^2:	0.975	0.978	0.978	0.983	0.987
Wu F ratio:	87.15	85.13	82.63	46.62	—
N:	1,415	1,415	1,415	1,371	1,415

Notes: Intercepts are not shown. Regressors include state and year dummy variables. Columns (i)–(iv) give two-stage least-squares (2SLS) estimates with C_{t-1} and C_{t+1} treated as endogenous. Column (v) gives an ordinary least-squares (OLS) estimate. The instruments in column (i) consist of the one-period lag and lead of price plus the other explanatory variables in the model. Column (ii) adds the current and one-period lag values of the state cigarette tax to the instruments; column (iii) further adds the one-period lead of the tax; and column (iv) further adds two additional lags of the price and tax variables. The Wu F ratios pertain to tests of the hypothesis that the OLS models corresponding to the first four columns are consistent. They all are significant at the 1-percent level.

and future consumption treated as endogenous variables and with future prices included in the set of instruments. The instruments used in column (i) consist of past and future prices (P_{t-1} and P_{t+1}, respectively) plus the other explanatory variables in the model. Column (ii) adds the current and one-period lag values of the state cigarette tax to the instruments, column (iii) further adds the one-period lead value of the tax, and column (iv) further adds two additional lags of the price and tax variables. As indicated above, 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.[6] Column (v) presents an OLS estimate of the rational-addiction model. As in Table 2, the Wu test rejects the hypothesis that OLS coefficients are consistent.

The estimated effects of past and future consumption on current consumption are significantly positive in the four 2SLS models in Table 3, and the estimated price effects are significantly negative in all cases.

[6] Inclusion of the future price as well as the future tax allows for the possibility that consumers have additional information about the price exclusive of tax or about the relationship between the price inclusive of tax and the tax.

TABLE 4—PRICE ELASTICITIES FOR TWO-STAGE LEAST-SQUARES MODELS (APPROXIMATE t STATISTICS IN PARENTHESES)

Elasticity	(i)	(ii)	(iii)	(iv)
Long-run	−0.734	−0.743	−0.747	−0.788
	(13.06)	(12.43)	(12.43)	(10.67)
Own price:				
Anticipated	−0.373	−0.361	−0.346	−0.306
	(10.73)	(11.13)	(10.86)	(9.87)
Unanticipated	−0.349	−0.322	−0.316	−0.262
	(9.97)	(10.09)	(10.10)	(9.20)
Future price, unanticipated	−0.050	−0.084	−0.058	−0.068
	(2.37)	(4.90)	(3.70)	(5.14)
Past price, unanticipated	−0.155	−0.133	−0.152	−0.144
	(8.99)	(8.01)	(9.80)	(9.43)
Short-run	−0.407	−0.436	−0.387	−0.355
	(9.34)	(9.51)	(9.69)	(8.80)

The positive and significant past consumption coefficient is consistent with the hypothesis that cigarette smoking is an addictive behavior. The positive and significant future consumption coefficient (though downward-biased) is consistent with the hypothesis of rational addiction and inconsistent with the hypothesis of myopic addiction.

Table 4 uses the 2SLS estimates from Table 3 to compute the elasticity of cigarette consumption with respect to various price changes defined in Section I and Appendix A at the sample means of price and consumption. Estimates of the long-run response to a permanent change in price in the first row range from −0.73 to −0.79 (average equals −0.75) and are at the high end of those in the literature that omit past and future consumption from the demand function. More important are the significant cross price effects. A 10-percent unanticipated reduction in current price leads to an increase of between 1.4 percent and 1.6 percent in next period's consumption (see row 5, which assumes that the price change is not anticipated until the current period) and to a 0.5–0.8-percent increase in the previous period's consumption (see row 4, which assumes that the price change is not anticipated until the previous period).

These estimates imply that a 10-percent decline in cigarette prices causes a short-run increase in cigarette consumption of 4 percent (see row 6), 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) and by 3 percent if it is unanticipated (see row 3). Each of these responses is less than 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 are not fully consistent with rational addiction, because the point estimates of the discount factor (β) are implausibly low: the ratio of the estimated coefficient of future consumption to the estimated coefficient of past consumption in the 2SLS models in Table 3 ranges from 0.31 to 0.64. These discount factors correspond to interest rates ranging from 56.3 percent to 222.6 percent. However, as we already indicated, uncertainty about future prices could account for the implausibly high interest rates implied by our estimates.

Although the OLS coefficients in column (v) of Table 3 are not consistent, they provide further support for the hypotheses that smoking is addictive (the coefficient of past consumption is positive and significant) and that consumers are rational (the coefficient of future consumption is positive, significant, and smaller than the coefficient of past consumption). The long-run price elasticity in the OLS model is −1.06, and the short-run elasticity is −0.34. The implied discount factor of 0.87 (interest rate of 14.9 percent) is quite reasonable. We return to the issue of inferring the discount factor from the estimates at the end of this section.

Table 5 contains estimates of rational-addiction demand functions that exclude the one-period lead value of price and the one-period lead value of the excise tax from the set of instruments. Model (i) in Table 5 employs the exogenous variables in the demand function and the first and second lag of price as instruments. Like the first model in Table 3, it is exactly identified. The last two models in Table 5 correspond to models (ii) and (iv) in Table 3 after future variables are deleted from the instruments. The last model in Table 5 is labeled model (iv) because it corresponds to model (iv) in Table 3.[7] As in Table 3, the Wu test rejects the hypothesis that OLS yields consistent estimates.[8]

The coefficients in Table 5 are very different from those in Table 3. The current-price and lagged-consumption coefficients fall dramatically, and the future-consumption coefficients rise dramatically (as Nelson and Startz [1990] would predict) when future variables are not used as instruments. The estimates in Table 5 still offer some support for the rational-addiction model, because the coefficient of future consumption is positive and significant. But the point estimates of the discount factor now are too high rather than too low: 5.30 in model (ii) and 8.14 in model (iv).[9] These discount factors correspond to negative interest rates of −81 percent and −88 percent, respectively.

The results in Table 5 are less supportive of the rational and myopic addiction models than are the results in Table 3. First, the implied discount factors in Table 5 are less plausible than those in Table 3. Second, the price coefficient in the first model in Table 5 is positive, and the corresponding coefficient in the third model, while negative, is not significant. Third, the estimate of the degree of addiction (θ), which is given by the coefficient of past consumption, in the second model in Table 5, is approximately one-third as large as the estimates of this parameter in Table 3. As a result, the short-run price elasticity of −0.76 in the second model in Table 5 is only 15-percent smaller than the long-run price elasticity of −0.90, while the short-run price elasticity is 50-percent smaller than the long-run price elasticity in all the models in Table 3. Finally, the estimates in Table 3 are much more stable across alternative sets of instruments than those in Table 5.

One way to choose between the estimates in Tables 3 and 5 is to perform Hausman

TABLE 5—TWO-STAGE LEAST-SQUARES ESTIMATES OF RATIONAL-ADDICTION MODELS, FUTURE PRICE AND TAX EXCLUDED FROM SET OF INSTRUMENTS, DEPENDENT VARIABLE = C_t (ASYMPTOTIC t STATISTICS IN PARENTHESES)

Independent variable	Model (i)	Model (ii)	Model (iv)
C_{t-1}	−0.235	0.139	0.109
	(1.03)	(2.25)	(1.69)
C_{t+1}	1.601	0.737	0.887
	(3.75)	(6.62)	(8.55)
P_t	0.865	−0.472	−0.164
	(1.39)	(2.33)	(0.89)
Y_t	−0.217	0.397	0.258
	(−0.67)	(3.19)	(2.14)
ℓdtax	0.393	0.038	0.115
	(2.30)	(0.77)	(2.39)
sdtimp	0.630	−0.559	−0.297
	(0.86)	(1.94)	(0.98)
sdtexp	1.571	1.325	−0.631
	(1.20)	(3.33)	(1.75)
R^2:	0.926	0.979	0.976
Wu F ratio:	39.35	51.85	42.36
N:	1,371	1,415	1,371

Notes: Intercepts are not shown. Regressors include state and year dummy variables. C_{t-1} and C_{t+1} are treated as endogenous. The instruments in model (i) consist of the first and second lag of price plus the other explanatory variables in the model. Model (ii) adds the current and one-period lag values of the state cigarette tax to the instruments and deletes the second lag of price, and model (iv) further adds two additional lags of the price and tax variables. The Wu F ratios pertain to tests of the hypothesis that the OLS estimates corresponding to the first three columns are consistent. They all are significant at the 1-percent level.

[7]Models (ii) and (iii) in Table 3 are the same when future variables are deleted from the instruments.

[8]An OLS demand function is not presented in Table 5 because it is identical to the one in Table 3.

[9]We do not compute the discount factor in model (i) because the coefficient of past consumption has the wrong sign.

tests (Jerry A. Hausman, 1978) of the hypothesis that future prices and taxes are legitimate estimates. Under the null hypothesis of perfect foresight (no measurement error in future prices), the estimates in both tables are consistent, but those in Table 3 are more efficient. Under the alternative hypothesis of measurement error in future prices, only the estimates in Table 5 are consistent. Therefore, Hausman's procedure amounts to a Wald test of the hypothesis that the coefficients in the second model in Table 5 are the same as the coefficients in the second or third model in Table 3, and that the coefficients in the third model in Table 5 are the same as those in the corresponding model in Table 3.

The computed X^2 statistics associated with these three tests are 24.4, 48.9, and 56.2, respectively. The first test has one degree of freedom since one instrument is excluded when future price is deleted. The second and third tests have two degrees of freedom since two instruments are excluded when the future price and the future tax are deleted. At the 1-percent level, the critical value of χ^2 is 6.6 in the first test and 9.2 in the second and third tests. Since the computed X^2 always greatly exceeds the critical value, the hypothesis that future values are legitimate instruments is rejected by this test given the maintained hypothesis that the past variables themselves are excluded from the demand equation.

However, before too much weight is placed on this rejection, one should recall the problems associated with the estimates in Table 5 that are not taken into account by the Hausman test. In particular, by limiting the set of instruments to poor predictors of future price and, therefore, to poor predictors of future consumption, it becomes difficult to sort out the past and future consumption effects. This is reflected in part by the dramatic increase in the standard errors of the past- and future-consumption coefficients, suggesting that the degree of multicollinearity rises when the future price and tax are not employed as instruments.

Therefore, it is useful to look at other ways to choose between the estimates in Tables 3 and 5. One way is to examine what happens if the true structural demand function was slightly different. Suppose that the second lag of consumption belongs in the true model with a coefficient of 0.1 or 0.2. When the first model in Table 3 is reestimated with either of these constraints imposed, the coefficient of future consumption remains unchanged at 0.14.[10] When the first model in Table 5 is reestimated with a constraint of 0.1 on the second lag of consumption, the coefficient of future consumption falls from 1.60 to 1.26. This coefficient drops even further to 0.88 when a constraint of 0.2 is used.

Similar results emerge with model (iv) in Tables 3 and 5. Since these models are overidentified, they can be estimated by including the second lag of consumption as an endogenous right-hand-side variable with no constraint imposed on its coefficient. When model (iv) in Table 3 is fit in this fashion, the coefficient of future consumption falls slightly from 0.23 to 0.20. With an imposed constraint of 0.1, this coefficient equals 0.22, and with a constraint of 0.2, it equals 0.21. The same exercises applied to model (iv) in Table 5 result in future consumption coefficients of 0.72, 0.80, and 0.72, respectively. These values should be compared to the coefficient of 0.89 in the table.

Although we have only considered the effect on the future-consumption coefficient, the results are similar when variations in the current-price coefficient are examined. In each case, models that use future prices and future taxes as instruments are much less sensitive to changes in the specification of the structural demand function than those that exclude these instruments. This is not surprising since the future-price variable provides variation that is correlated with future consumption and not highly correlated with potentially omitted past price and consumption variables.

A final way to choose between the estimates in Tables 3 and 5 is to simulate the

[10]The coefficient in Table 3 is 0.135. The same coefficient is 0.139 in a model that omits the second lag of consumption but is estimated on the reduced sample that results when the constraint is imposed.

impact of overstating the covariance between expected future price and expected future consumption. Consider the exactly identified model estimated in the first column in Table 3. Let c be current consumption, f be expected future consumption, ℓ be the first lag of consumption, p be expected future price, z be past price, and σ_{ij} be the covariance between any two of these variables net of all other variables in the demand function (current price, income, the three smuggling measures, and the state and time dummies).[11] If f and p were observed, the two-stage least-squares coefficients of future consumption (θ_f) and past consumption (θ_ℓ) would be

$$(6) \quad \theta_f = (\sigma_{cp}\sigma_{\ell z} - \sigma_{\ell p}\sigma_{cz})/(\sigma_{fp}\sigma_{\ell z} - \sigma_{\ell p}\sigma_{fz})$$

$$(7) \quad \theta_\ell = (\sigma_{cz}\sigma_{fp} - \sigma_{fz}\sigma_{cp})/(\sigma_{fp}\sigma_{\ell z} - \sigma_{\ell p}\sigma_{fz}).$$

Let π be actual future price and let a be actual future consumption. Note that $\pi = p + u$ and $a = f + \varepsilon$, where the forecast error in future consumption (ε) is negatively related to the forecast error in future price (u). Since u is uncorrelated with current or past variables, the only covariance that is affected when π replaces p and a replaces f is that between π and a. In particular,

$$(8) \quad \sigma_{fp} = k\sigma_{a\pi} \qquad k = [1 - (\sigma_{\varepsilon u}/\sigma_{a\pi})].$$

Presumably, k is less than 1. Therefore, if $\sigma_{a\pi}$ rather than σ_{fp} is used in equations (10) and (11), the coefficient of future consumption and the ratio of the coefficient of future consumption to the coefficient of past consumption are understated.

Table 6 presents estimates of θ_f, θ_ℓ, and the ratio of the long-run price elasticity to the short-run price elasticity for alternative assumed values of k. As long as k is at least as large as 0.75 (the forecast error covariance is no larger than 25 percent of the total covariance), the true estimates are similar to those in the first column of Table 3. These latter estimates assume that $k = 1$, or that the forecast error covariance is zero. Not surprisingly, if one attempts to reconcile the large divergence between the estimates in Tables 3 and 5 based only on imperfect information concerning future prices, it is necessary to assume that the forecast error covariance is extremely (and in our view unreasonably) large. We have already pointed out a better way to reconcile these estimates. This is to use the empirical fact that past prices and taxes are poor predictors of future prices and relatively good predictors of potentially omitted past effects. This makes these variables poor predictors of future consumption.

The conclusions to be drawn from these tests of the estimates in Tables 3 and 5 depend on one's priors. If one believes that the structural demand function is correctly specified, and that the errors in forecasting future cigarette prices are enormous, then the estimates in Table 5 are preferable. However, if one believes that the structural demand function is misspecified—if only slightly—and that consumers do have relevant information to forecast future cigarette prices, then the estimates in Table 3 are clearly preferable. For the reasons already given, we prefer the second interpretation, which is supportive of the rational-addiction model. It should be noted that none of the

TABLE 6—FUTURE CONSUMPTION COEFFICIENT (θ_f), PAST CONSUMPTION COEFFICIENT (θ_ℓ), AND RATIO OF LONG-RUN TO SHORT-RUN PRICE ELASTICITY, CORRECTED FOR FORECAST ERROR

k	θ_f	θ_ℓ	Ratio of long-run to short-run price elasticity
1.000	0.135	0.418	1.803
0.750	0.179	0.399	1.762
0.500	0.268	0.360	1.676
0.400	0.336	0.330	1.608
0.333	0.407	0.299	1.535

Notes: In the first column, k is the ratio of the partial covariance between expected future consumption and expected future price to the partial covariance between actual future consumption and actual future price, with current price, income, the three smuggling measures, and the state and time dummies held constant.

[11]That is, c, f, ℓ, p, and z are residuals from, for example, a regression of actual current consumption on the exogenous variables in the demand function.

TABLE 7—CURRENT PRICE COEFFICIENTS, LAGGED CONSUMPTION COEFFICIENTS, LONG-RUN PRICE ELASTICITIES, AND SHORT-RUN PRICE ELASTICITIES IN RESTRICTED MODELS

		Panel A: *Future Price or Future Price and Future Tax Included as Instruments*					Panel B: *No Future Variables Included as Instruments*				
β	Model	Marginal significance level of restriction	P_t	C_{t-1}	Long-run price elasticity	Short-run price elasticity	Marginal significance level of restriction	P_t	C_{t-1}	Long-run price elasticity	Short-run price elasticity
0.70	(ii)	0.727	−1.220	0.360	−0.742	−0.445	0.000	−1.105	0.385	−0.755	−0.426
	(iv)	0.054	−0.925	0.426	−0.792	−0.395	0.000	−0.822	0.449	−0.820	−0.376
0.75	(ii)	0.548	−1.214	0.351	−0.743	−0.452	0.000	−1.084	0.378	−0.756	−0.430
	(iv)	0.021	−0.919	0.415	−0.792	−0.404	0.000	−0.803	0.440	−0.824	−0.384
0.80	(ii)	0.400	−1.208	0.342	−0.742	−0.458	0.000	−1.063	0.372	−0.759	−0.436
	(iv)	0.008	−0.913	0.404	−0.790	−0.413	0.000	−0.781	0.432	−0.829	−0.391
0.85	(ii)	0.285	−1.203	0.334	−0.743	−0.465	0.000	−1.044	0.366	−0.763	−0.442
	(iv)	0.003	−0.908	0.394	−0.791	−0.421	0.000	−0.761	0.424	−0.833	−0.398
0.90	(ii)	0.199	−1.199	0.326	−0.743	−0.472	0.000	−1.025	0.359	−0.761	−0.446
	(iv)	0.001	−0.904	0.385	−0.795	−0.431	0.000	−0.743	0.416	−0.837	−0.405
0.95	(ii)	0.136	−1.196	0.318	−0.743	−0.478	0.000	−1.007	0.353	−0.763	−0.451
	(iv)	0.000	−0.901	0.375	−0.791	−0.439	0.000	−0.725	0.409	−0.845	−0.414

Notes: All price and lagged consumption coefficients and all elasticities are statistically significant at all conventional levels of confidence. For panel A, the instruments in model (ii) are the one-period lag of price, the one-period lead of price, the current state excise tax, the one-period lag of the tax, and the exogenous variables in the demand function. Model (iv) adds the one-period lead of the tax and the two-period lags of the tax and price to the set of instruments. For panel B, the instruments in model (ii) are the one-period lag of price, the current tax, the one-period lag of the tax, and the exogenous variables in the demand function. Model (iv) adds the two-period lags of the tax and price to the set of instruments. The marginal significance levels of the restrictions are based on a Lagrange multiplier (LM) test.

models in either table supports the myopic-addiction model. In fact the results in Table 5 reject the rational model because they imply that consumers put *too much* weight on future consumption.

Even if the rational-addiction model is accepted, it is not possible to infer the discount rate reliably from these cigarette data. One approach is simply to impose the discount factor a priori. We do this in Table 7, by imposing six alternative discount factors ranging from 0.70 to 0.95 (interest rates ranging from 5.3 percent to 42.9 percent) in estimating models (ii) and (iv). That is, we constrain the coefficient of future consumption to equal β multiplied by the estimated coefficient of past consumption. We impose this constraint both in the specifications that include the future price and the future tax as instruments, and in the specifications that exclude these variables as instruments.

The table presents price coefficients, past-consumption coefficients, long-run price elasticities, and short-run price elasticities that emerge from the restricted estimates. The marginal significance level of the restriction, based on a Lagrange multiplier (LM) test, also is indicated. Regardless of the discount factor imposed, the long-run price elasticities are very similar to each other and to those in Table 4. The same comment applies to the short-run price elasticities. Moreover, the specifications that employ the future price and the future tax as instruments yield elasticities that are almost identical to those that exclude these two instruments.[12]

[12] When future variables are used as instruments, the restriction is not significant (the imposed discount factor is valid) at the 1-percent level in eight out of 12

Discount factors of 0.85 and 0.90 are very similar to the discount factor of 0.87 implied by the OLS regression in Table 5. Yet the application of the Wu test to the constrained estimates in Table 7 that impose these discount factors rejects the hypothesis that OLS is consistent. When the imposed discount factor is 0.85, the F ratios in panel A are 167.5 in model (ii) and 77.8 in model (iv). The corresponding F ratios in panel B are 72.3 and 27.7 When the imposed discount factor is 0.90, the F ratios in panel A are 167.5 in model (ii) and 78.0 in model (iv). The corresponding F ratios in panel B are 68.0 and 25.2. All are significant at the 1-percent level. The eight models in Table 7 with discount factors of 0.85 and 0.90 imply an average long-run price elasticity of -0.78 and an average short-run price elasticity of -0.44. We are more confident in these estimates than in the long-run elasticity of -1.06 and the short-run elasticity of -0.34 associated with the OLS regression in Table 3.

The results in Tables 3, 5, and 7 suggest that the data are not rich enough to pin down the discount factor with precision. This is not surprising. Estimates of consumer discount factors from studies of aggregate consumption, the consumption of specific goods, or the consumption of leisure over time vary considerably. Some of these estimates imply extremely high interest rates, while others imply very low and even negative interest rates (e.g., Lars Peter Hansen and Kenneth J. Singleton, 1983; N. Gregory Mankiw et al., 1985; V. Joseph Hotz et al., 1988; Olympia Bover, 1991; Larry G. Epstein and Stanley E. Zin, 1991). Nevertheless, it is reassuring that our estimates of the basic parameters of the model are not sensitive to the choice of alternative discount factors. Moreover, in the specifications with the future price and tax as instruments, we cannot reject the hypothesis (at the 1-percent level) that the discount factor is as high as 0.90 or 0.95 in two of four cases. Finally, when we compensate for the narrow set of instruments that results from the deletion of future variables by imposing a discount factor, the estimates of short-run and long-run price elasticities are not sensitive to the instruments used to obtain them.

Frank Chaloupka (1991) provides further evidence in support of a 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 finds a short-run price elasticity (-0.20) that is less than half of the long-run price elasticity of -0.45. His significant future-consumption coefficient is further evidence against myopic addiction.

V. Monopoly and Addiction

The organization of the cigarette industry has been studied frequently and shown to be highly concentrated (Joe S. Bain, 1968; Daniel A. Sumner, 1981; Elie Appelbaum, 1982; Paul A. Geroski, 1983; Robert H. Porter, 1986). Two companies (R. J. Reynolds and Philip Morris) account for about 70 percent of U.S. output, and the studies just cited conclude in general that cigarette companies have significant monopoly power. Discussions of pricing by cigarette companies have not paid attention to the habitual aspects of cigarette smoking, even though that greatly affects optimal monopoly pricing and other company policies.

To illustrate the relation between pricing and addiction, elsewhere we develop a simple monopoly pricing model (see Becker et al., 1990; also see the extensions of our analyses by Gary Fethke and Raj Jagannathan [1991] and by Mark H. Showalter [1991]). The main implications are quite intuitive. In each period a monopolist sets a price where marginal revenue is below marginal cost, as long as consumption is addictive and future prices tend to exceed future marginal costs due to the monopoly power. The reason is

cases, and it is not significant at the 5-percent level in seven out of 12 cases. On the other hand, when future variables are not used as instruments, the restriction is significant in every case at any conventional level of confidence. These results are to be expected since the estimates in Table 5 imply discount factors that exceed 1.

that future profits are higher when current consumption is larger and current price is lower, because greater current consumption raises future consumption. As it were, a monopolist may lower price to get more consumers "hooked" on the addictive good. The optimal marginal revenue is lower relative to marginal cost when the good is more addictive, future demand is stronger, and future price minus cost is bigger. With a sufficiently large positive effect on future demand of a lower current price, a monopolist might choose a current price that is below current cost, or a price in the inelastic region of demand.

This analysis which incorporates addiction into pricing policy may be helpful in understanding the rise in cigarette prices in recent years. Much of the drop in demand for cigarettes since 1981 documented by Jeffrey E. 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. 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 (see Harris, 1987; Amy Dunkin et al., 1988). Indeed, according to Stephen J. Adler and Alix M. 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. An increase in current prices would raise cigarette companies' profits in the short run if they were pricing below the current profit-maximizing point (in order to raise future demand through the addictive effect of greater current smoking). Addictive behavior can also explain why current prices rise: the decline in future demand for smoking reduces the gains from maintaining a lower price to stimulate future consumption.

Incorporation of the addictive aspects of smoking also leads to a test of whether the cigarette industry is oligopolistic or competitive. If smokers are addicted and if the industry is oligopolistic, an expected rise in future taxes and hence in future prices induces a rise in current prices even though current demand falls when future prices are expected to increase. This cannot happen in simple models of competitive behavior.

A higher federal excise tax on cigarettes was widely expected to go into effect at the beginning of 1983—an example of an instance where consumers had prior information about future tax increases. 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 a price increase in 1982 may have occurred even if oligopolistic cigarette producers had no such coordinating problems, because the higher future cigarette tax reduced future demand and, hence, the gain from lowering current price.

APPENDIX A: SOLUTION OF DIFFERENCE EQUATION AND PRICE EFFECTS

The solution of the difference equation (4) is

$$\text{(A1)}\quad C_t = \frac{1}{\theta\phi_1[\phi_2-\phi_1]}\sum_{s=1}^{\infty}\phi_1^s h(t+s) + \frac{1}{\theta\phi_2[\phi_2-\phi_1]}\sum_{s=0}^{\infty}\phi_2^{-s}h(t-s) + \frac{1}{\phi_2^t}\left(C^0 - \frac{1}{\theta\phi_1[\phi_2-\phi_1]}\sum_{s=1}^{\infty}\phi_1^s h(s)\right)$$

where

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

$$\phi_1 = \frac{1-(1-4\theta^2\beta)^{1/2}}{2\theta}$$

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

with $4\theta^2\beta < 1$ for stability.

Equation (A1) 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

$$\text{(A2a)}\quad \left.\frac{dC_t}{dP_\tau}\right|_{\tau>t} = \frac{\theta_1\phi_1^{\tau-t}}{\theta[\phi_2-\phi_1]}\left[1-\left(\frac{\phi_1}{\phi_2}\right)^t\right] \lesseqgtr 0 \quad \text{as } \theta \gtrless 0$$

$$\text{(A2b)}\quad \left.\frac{dC_t}{dP_\tau}\right|_{\tau<t} = \frac{\theta_1\phi_2^{\tau-t}}{\theta[\phi_2-\phi_1]}\left[1-\left(\frac{\phi_1}{\phi_2}\right)^\tau\right] \lesseqgtr 0 \quad \text{as } \theta \gtrless 0$$

$$\text{(A2c)}\quad \frac{dC_t}{dP_t} = \frac{\theta_1}{\theta[\phi_2-\phi_1]}\left[1-\left(\frac{\phi_1}{\phi_2}\right)^t\right] < 0.$$

To obtain the completely unanticipated price effect, set t or τ on the right-hand side of equation (A2) equal to 1. To obtain the fully anticipated price effect, let t or τ approach infinity.

The effect on consumption in period t of a permanent reduction in price beginning in period t, which we denote as dC_t/dP_t^*, is given by

$$\text{(A3)}\quad \frac{dC_t}{dP_t^*} = \frac{\theta_1\left[1-(\phi_1/\phi_2)^t\right]}{\theta(1-\phi_1)(\phi_2-\phi_1)}.$$

With t equal to 1, the equation gives the effect on current consumption of a completely unanticipated permanent reduction in price. This effect is

$$\text{(A4)}\quad \frac{dC_t}{dP_t^*} = \frac{\theta_1}{\theta(1-\phi_1)\phi_2}.$$

Equation (A4) 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 *all* periods on consumption in period t is

$$\text{(A5)}\quad \frac{dC_t}{dP} = \frac{\theta_1\phi_2^{-t}}{\theta(\phi_2-\phi_1)} \times\left[\frac{\phi_2^t}{\phi_2-1}-\frac{1-\phi_1^t}{1-\phi_1}\right] + \frac{\theta_1\left[1-(\phi_1/\phi_2)^t\right]}{\theta(1-\phi_1)(\phi_2-\phi_1)}.$$

The limit of equation (A5) as t goes to infinity equals the long-run effect of a permanent reduction in price:

$$\text{(A6)}\quad \frac{dC_\infty}{dP} = \frac{\theta_1}{\theta(1-\phi_1)(\phi_2-1)}.$$

Appendix B: 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, 1955–1969
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 cigarette 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 2, 3, 5, and 7 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.

The effects of short-distance casual smuggling are measured by two variables: one for imports and one for exports. The importing variable is

$$\text{sdtimp}_i = \sum_j k_{ij}(T_i - T_j)$$

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 (Bureau of the Census, 1973), and the summation is taken over neighboring states with lower tax rates. This is equivalent to setting the tax differential equal to zero if $T_i \le T_j$. The exporting variable is given by

$$\text{sdtexp}_i = \sum_j k_{ji}(T_i - T_j)(\text{POP}_j/\text{POP}_i)$$

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. Here the summation is taken over neighboring states with higher tax rates. This is equivalent to setting the tax differential equal to zero if $T_i \ge T_j$. The reason that the population ratio is used in the export variable is that *total* exports from state i to state j should depend on the part of the population of state j living near state i or POP_j multiplied by k_{ji}. Since the 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 population figures are year-specific. They were taken from the 1960, 1970, and 1980 Censuses of Population for census years and from the Bureau of the Census (1985) for other years (see the reference just cited for the complete list of sources). For noncensus years, the population was given as of July 1, and for census years, it was given as of April 1. The latter was interpolated to July 1 using state-specific exponential-growth trends between, for example, April 1, 1980, and July 1, 1981. Then population in fiscal year t was defined as a simple average of population as of July 1 in years $t-1$ and t.

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

$$\ell\text{dtax}_i = (T_i - T_{\text{KY}}) \quad \text{if importing from Kentucky}$$

$$= z_{\text{NC}}(T_i - T_{\text{NC}}) + z_{\text{VA}}(T_i - T_{\text{VA}})$$

$$\text{if importing from North Carolina and Virginia}$$

$$= \sum_j (T_{\text{KY}} - T_j)(\text{POP}_j/\text{POP}_{\text{KY}}) \quad \text{for Kentucky}$$

$$= z_i\left[\sum_j (T_i - T_j)(\text{POP}_j/\text{POP}_i)\right]$$

$$\text{for } i = \text{NC, VA}.$$

The weights used for states that import from North Carolina and Virginia are the shares of value added accounted for by each in the production of cigarettes in these two states combined. That is,

$$z_{\text{NC}} = \frac{(\text{value added in NC})}{(\text{value added in NC} + \text{value added in VA})}.$$

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).

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