NBER WORKING PAPER SERIES

MEN, WOMEN, AND ADDICTION: THE CASE OF CIGARETTE SMOKING

Frank J. Chaloupka

Working Paper No. 3267

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 1990

This paper is part of NBER's research program in Health Economics. Any opinions expressed are those of the author not those of the National Bureau of Economic Research.

NBER Working Paper #3267
February 1990

MEN, WOMEN, AND ADDICTION: THE CASE OF CIGARETTE SMOKING

ABSTRACT

Cigarette demand equations, derived from the Becker-Murphy model of rational addictive behavior, are estimated separately for men and women. These demand equations account for the reinforcement, tolerance, and withdrawal factors characterizing addictive consumption. Results obtained from these demand equations support the hypothesis that cigarette smoking is an addictive behavior. Particularly interesting are the findings that men are responsive to changes in the price of cigarettes, with a long run price elasticity centered on -0.60, while women are virtually unresponsive to price changes. Men, however, are found to behave more myopically than women.

Frank J. Chaloupka
Department of Economics
University of Illinois at Chicago
Chicago, IL 60680
and
NBER
269 Mercer St, 8th Floor
New York, NY 10003

I. INTRODUCTION

Recently, economists have modeled addictive consumption as a rational behavior. These models capture the distinction between addictive consumption and other consumption by recognizing that, for addictive goods, current consumption depends on the level of past consumption. This time dependence of consumption incorporates the notions of tolerance, reinforcement, and withdrawal characteristic of addictive consumption. Tolerance allows for a reduced effect of current consumption as past consumption is larger. Reinforcement implies a learned response to past consumption. Finally, withdrawal is a negative physical reaction as consumption is terminated.

This paper uses demand equations derived from the Becker-Murphy [1988] model of rational addiction to estimate separate cigarette demand equations for men and women which explicitly take account of the addictive nature of cigarette smoking. This is the first analysis of differences in male/female behavior in the rational addiction framework. Chaloupka [1988, 1989], and Becker, Grossman, and Murphy [1988] have estimated cigarette demand equations in the context of the Becker-Murphy addictive model.

Men and women have responded differently to the policy initiatives of the anti-smoking campaign since the release of the Surgeon General's report on the health consequences of cigarette smoking 25 years ago. Historically, men had always smoked at much higher rates than women, but the differences between the two have become much smaller since 1964. At that time, 52.9 percent of men were smokers, while only 34.1 percent of women were smokers [USDHHS, 1986]. During the years which followed, significant progress was made in reducing smoking participation among men, with only limited progress made in reducing the fraction of women who smoked. By 1985, the male smoking participation rate had fallen to 33 percent, while the comparable female rate had fallen to only 28 percent. Moreover, surveys show that fewer men are initiating smoking today than there were twenty years ago, while the fraction of women initiating smoking today is identical to that in 1970 [USDHHS, 1986].

In addition to the observed differences in the historical smoking patterns of men and women, several other differences have been described. For example, women face additional health risks from cigarette smoking which are complicated by pregnancy. In particular, smoking during pregnancy leads to lower birth weight, a greater likelihood of spontaneous abortion, increased incidence of bleeding during pregnancy, and a higher rate of still births. Children of women who smoke during pregnancy have greater neonatal and infant mortality rates than those born to nonsmokers, including an increased risk of the sudden infant death syndrome. Also, there can be adverse effects on the child's long-term growth, intellectual development, and behavioral characteristics due to the mother's smoking during pregnancy [USDHHS, 1980].

Additionally, there is a synergy between cigarette smoking and the use of oral contraceptives containing estrogen which increases the risk of suffering a stroke or heart attack [USDHHS, 1980].

Similarly, the Surgeon General notes that "women may not start smoking, continue to smoke, quit smoking, or fail to quit smoking for precisely the same reasons as men" [USDHHS, 1980]. For example, women smokers have been much less successful in smoking cessation than their male counterparts, with women in organized cessation programs experiencing more severe withdrawal symptoms than men [Ashton and Stepney, 1982]. Also, women tend to smoke "low tar and nicotine cigarettes, smoke fewer cigarettes per day, and inhale less deeply than do men" [USDHHS, 1980]. Also, differences in nicotine metabolism between men and women have been suggested. Analogously, women appear to smoke more in stressful situations (to relax themselves) than in situations where they are bored (to stimulate themselves), while the opposite is observed among men.

Finally, in those studies by economists which consider the demand for cigarettes by men and women separately, significant but conflicting differences in the responses to price and income changes have been estimated. For example, Atkinson and Skegg [1973] find that men are unresponsive to changes in cigarette prices but do respond to the negative publicity on cigarette smoking. Mullahy [1985], on the other hand, finds that men are more responsive to changes in price than women. Mullahy also observes that cigarette smoking is an economically superior behavior for men while it is an economically inferior behavior for women.

II. THEORETICAL MODEL

This work uses the Becker-Murphy model of rational addiction. In this model, tastes are constant and the individual is assumed to be fully rational. This is in contrast to other economic models of addictive behavior which treat addicts as myopic and/or having endogenous tastes. While assuming complete rationality appears strong, it seems more consistent than the assumption underlying the myopic models. In myopic models, individuals are assumed to be aware of the dependence of current consumption on past consumption but ignore the resulting dependence of future consumption on current consumption when making current decisions.

At any moment in time, an individual's utility is assumed to be a function of three factors:

(1) $U(t) = U[C(t), A(t), Y(t)],$

$C(t)$ is the current consumption of the addictive good, cigarettes. $A(t)$ is the "addictive stock," or depreciated sum of all past cigarette consumption, at time t. $Y(t)$ is a composite of all other factors affecting utility. Current cigarette consumption is assumed to have a positive effect on utility ($U_C>0$). This can be used to illustrate withdrawal, since total utility falls when current cigarette consumption is reduced. Due to the combined effects of tolerance and the health consequences of smoking, accumulated past consumption is assumed to have a negative effect on current utility ($U_A<0$). To capture reinforcement effects in consumption, assume that increases in the addictive stock increase the marginal utility of current consumption ($U_{CA}>0$). Finally, for concavity, it is assumed that all second partials are negative ($U_{ii}<0$, i=A, C, Y).

Following Becker and Murphy, a simple investment function for the addictive stock is specified as:

$$(2) \qquad \dot{A}(t) = C(t) - \delta A(t),$$

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

Assuming a time additive utility function, a constant rate of time preference, σ, and an infinite lifetime, the lifetime utility function is:

$$(3) \qquad U = \int_0^\infty e^{-\sigma t} U[C(t), A(t), Y(t)]\, dt.$$

Rational behavior implies maximization of this function subject to a lifetime budget constraint. Ignoring the allocation of time over the life-cycle, treating Y(t) as a composite good whose price, $P_Y(t)$, is the numeraire, and assuming perfect capital markets, the appropriate budget constraint is:

$$(4) \qquad \int_0^\infty e^{-rt}[Y(t) + P_C(t)C(t)]\, dt \le R(0),$$

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

Maximizing (3) subject to (2), (4), and an initial stock condition yields the following first order conditions:

$$(5) \qquad U_Y(t) = \mu e^{-(\sigma-r)t}, \qquad \text{and:}$$

(6) $$U_C(t) = \mu\pi_C(t),$$

where:

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

$\pi_C(t)$ can be thought of as the full price of the addictive good, and consists of two parts: the money price, $P_C(t)$, appropriately discounted, and the discounted future utility costs, or shadow price, of the addictive stock. Since $U_A(t)$ is always negative, the full price of smoking is greater than its money price. The larger the rate of depreciation, the lower the shadow price of the stock, resulting in an increase in consumption. Similarly, the greater the rate of time preference, the lower the full price of the addictive good, cigarettes, and, therefore, the greater its consumption. Finally, the shadow price of the stock is rising as the level of the stock increases, since $U_{AA} < 0$.

III. EMPIRICAL FRAMEWORK

Following Becker and Murphy [1988] and Becker, Grossman, and Murphy [1988], a quadratic utility function in the three arguments, Y(t), C(t), and A(t) is assumed. The assumption is also made that the individual's rate of time preference is equal to the market rate of interest (that is, σ=r). The resulting instantaneous utility function is:

$$(8) \quad U(t) = b_Y Y(t) + b_C C(t) + b_A A(t) + \frac{U_{YY}}{2} Y(t)^2 + \frac{U_{CC}}{2} C(t)^2 + \frac{U_{AA}}{2} A(t)^2 + U_{YA} Y(t)A(t) + U_{CA} C(t)A(t) + U_{YC} Y(t)C(t).$$

Maximizing out with respect to Y(t), converting to discrete time, and using the resulting first order conditions for C(t) and A(t), the following demand equations are derived (for a detailed derivation, see the mathematical appendix):

$$(9) \quad C(t) = \beta_0 + \beta_1 P_C(t) + \beta_2 P_C(t-1) + \beta_3 P_C(t+1) + \beta_4 C(t-1) + \beta_5 C(t+1)$$

and:

$$(10) \quad C(t) = \phi_0 + \phi_1 P_C(t) + \phi_2 P_C(t+1) + \phi_3 C(t+1) + \phi_4 A(t) \ .$$

In both demand equations, current consumption is predicted to be negatively related to the current price of cigarettes, but positively related to both past (when included) and future prices. In the Becker-Murphy model, addiction implies that consumption in different time periods are complements. Thus, current consumption, if the good is addictive, is expected to be positively related to future consumption. Similarly, when lagged consumption is included, current consumption is predicted to be positively related to lagged consumption. However, when the stock enters, no prediction can be made concerning the direction of the relationship between it and current consumption.[1] Finally, these demand equations hold the marginal utility of wealth constant.[2]

Mullahy's estimates for a myopic model of cigarette smoking support the hypothesis that cigarette smoking is an addictive behavior for both men and women. Becker, Grossman, and Murphy's [1988] application of Becker and Murphy's rational addiction model to a pooled data set of the states of the U.S. over time supports the hypothesis that cigarette smoking is an addictive behavior and finds some evidence that individuals behave rationally. Chaloupka [1989] estimates these demand equations using data on individuals in the United States, finding support for the hypotheses that cigarette smoking is an addictive behavior and that individual's do not behave myopically. The estimates presented below are the first to examine differences in the cigarette smoking behavior of men and women in the context of the Becker-Murphy model of rational addiction.

IV. DATA

The data employed in the estimation of these demand equations come from the Second National Health and Nutrition Examination Survey (NHANES2). This is a national survey of approximately 28,000 people ages 6 months to 74 years conducted from 1976 to 1980 by the National Center for Health Services Research. Population groups thought to be at high risk from malnutrition were over-sampled. Each individual completed detailed questionnaires on their health histories and most underwent a comprehensive physical examination. Data on dietary patterns, including alcohol and cigarette consumption, was also collected.

Based on an individual's county and state of residence, cigarette price and excise tax series were added to the data set. The cigarette price is a weighted average statewide price for a pack of twenty cigarettes based on the prices of single packs, cartons, and vending machines sales, inclusive of state sales taxes and, where applicable, local excise taxes, where the weights are the national proportions of each type of sale. Due to large differences in cigarette prices across states (arising from substantial differences in excise tax rates) smokers residing in high tax localities have an incentive to purchase cigarettes in a low tax locality. This incentive depends on the price difference and the costs of purchasing and transporting the cigarettes from one area to another, and increases the closer an individual lives to a lower price locality. Failing to account for this border crossing phenomenon would result in estimated price coefficients biased towards zero. To capture this casual smuggling, an equally weighted average of the "border price" (the lowest price within twenty-five miles of the individual's county of residence) and the local price of cigarettes is used for cigarette price. All prices and taxes are deflated by the national monthly Consumer Price Index and a local price index developed by Mullahy based on the procedure described by Fuchs, Michael, and Scott [1979].

To estimate demand equation (9), consumption in three consecutive periods is required, but only two consecutive periods are provided in the survey data. In NHANES2, data were collected on current cigarette consumption, lagged cigarette consumption, and consumption at the time when the individual smoked his or her greatest average daily quantity. The timing of maximum consumption, however, is not reported. Also available are the number of years prior to the interview the individual began smoking regularly and the number of years, for former smokers, that the individual has not smoked. The following strategy is employed in the estimation of demand equation (9). What is reported as current consumption C(t) is treated as future consumption $C^*(t+1)$ and what is reported as lagged consumption C(t-1) is treated as current consumption $C^*(t)$, requiring an estimate of $C^*(t-1)$ (actual C(t-2)). For never-smokers, $C^*(t-1)$ is equal to zero. Similarly, for individuals who either began smoking less than two years prior to their interview or stopped smoking two or more years prior to their interview, $C^*(t-1)$ is equal to zero. For the remainder, individuals smoking two years prior to their interview (about one-fourth of the sample), maximum consumption is used as a proxy for $C^*(t-1)$.[3]

To estimate demand equation (10), current and future consumption and a measure of the addictive stock are required. Current and future consumption are obtained as described above. An estimate of the addictive stock is obtained as follows. Recalling the assumptions concerning the formation of the addictive stock and assuming that the initial stock is zero, the stock at time t is:

$$(11) \qquad A(t) = \Sigma_{i=0}^{t-1} (1-\delta)^{t-1-i} C(i) \quad .$$

Defining the term $(1-\delta)^{t-1-i}$ as D(i), and using the definition for covariance, equation (11) can be rewritten as follows:

$$(12) \qquad A(t) = \Sigma_{i=0}^{t-1} D(i)C(i) \quad = t\bar{D}\bar{C} + t\text{Cov}[D(i), C(i)]$$

$$= \bar{C} \left[\frac{1 - (1-\delta)^t}{\delta} \right] + t\text{Cov}[D(i), C(i)]$$

where $\bar{D}$ and $\bar{C}$ are the means of D(i) and C(i), respectively.

The covariance term is assumed to be zero based on observed lifetime smoking patterns. Thus, to estimate the stock, mean cigarette consumption, an assumed constant rate of depreciation, and the number of years the individual has smoked are required. For never-smokers, the stock is zero. For smokers, maximum consumption is used as a proxy for mean consumption, with a modified version of (12) used to compute the stock for former smokers. Finally, various depreciation rates are assumed and the sensitivity of the results to these rates is discussed below.[4]

In each equation, the individual's age, age squared, race, real family income, and a measure of educational attainment are included as independent variables. Race is measured by a pair of dichotomous variables, the first is equal to one if the individual is black and is equal to zero otherwise, and the second is equal to one if the individual is neither black nor white and is equal to zero otherwise. The income data reported in the survey is categorical. The midpoint of each range is used as an approximation for income, with the exception of the highest category ($25,000 and over) for which $30,000 is used. The resulting measure is then deflated by the annual CPI for the month during which the individual was interviewed and the state CPI. Also included in each equation as a measure of educational attainment is the number of years of formal schooling completed (with an upper bound of 17 for those with 17 or more years of formal education). Finally, a dichotomous variable equal to one if the individual is a native American and equal to zero otherwise is included due to the tax-exempt status of cigarette sales on Indian reservations. This variable should be positively related to smoking as it indicates (possibly) that the individual faces a lower price for cigarettes.

Also included in the estimated demand equations are indicators of marital status and labor force status. Marital status is captured by a set of dichotomous variables indicating that the individual is widowed, divorced, separated, or single, with married as the excluded category. To measure labor force status, two dichotomous variables indicating non-participants and unemployed participants are used. These variables are included in an attempt to capture the effects of stressful life-cycle events, such as divorce, separation, and unemployment, on cigarette smoking. In the Becker-Murphy model, stressful life-cycle events are predicted to either lead to greater consumption of the addictive good or to induce individuals who were not consumers to initiate consumption and, hence, become addicted.

V. RESULTS

Estimates of demand equations (9) and (10) are reported in Table 1. Panel A of Table 1 contains the results for men, while the estimates obtained for women are contained in Panel B. Column 1 of the two panels in Table 1 contains the estimates of equation (9) where no assumption is made about the rate of depreciation on the addictive stock. Column 2 of the two panels in Table 1 contains the estimates of equation (9) assuming a 100% rate of depreciation on the addictive stock (resulting in the exclusion of past and future prices from the equation). Columns 3 and 4 contain estimates of equation (10) assuming rates of depreciation of eighty and sixty percent respectively. All equations are estimated using Instrumental Variables procedures rather than Ordinary Least Squares procedures due to the endogeneity of past and future consumption in equation (9), and the addictive stock and future consumption in equation (10).[5] In equation (9), current consumption is specified as a function of one lag of consumption, one lead of consumption, and lagged, current, and future cigarette prices, implying that current consumption is independent of other past and future prices, suggesting that further lags and leads of prices are suitable instruments for lagged and led consumption. Similar arguments can be made for using several lags and leads of prices as instruments for the addictive stock in equation and future consumption in equation (10). Thus, the set of instruments employed includes the exogenous variables affecting consumption, four lags of price, current price, and four leads of price, and

Table 1[a]

Two-Stage Least Squares Estimates of Cigarette Demand Equations

Independent Variable	Panel A: Males No Assumed Rate	δ=100%	δ=80%	δ=60%
Intercept	0.385	0.351	0.742	1.378
	(0.36)	(0.34)	(0.72)	(1.32)
Price(t-1)	11.153	----	----	----
	(1.05)	----	----	----
Price(t)	-20.067	-5.131	-9.055	-8.142
	(-1.61)	(-2.34)	(-1.24)	(-1.10)
Price(t+1)	3.926	----	4.125	3.436
	(0.53)	----	(0.58)	(0.47)
Lagged Consumption	0.549	0.543	----	----
	(3.74)	(3.86)	----	----
Future Consumption	0.182	0.225	0.256	0.272
	(0.84)	(1.14)	(1.28)	(1.36)
Addictive Stock	----	----	0.418	0.308
	----	----	(3.69)	(3.60)
Age	0.163	0.135	0.113	0.073
	(1.77)	(1.60)	(1.34)	(0.86)
Age Squared	-0.002	-0.001	-0.001	-0.001
	(-1.56)	(-1.36)	(-1.16)	(-0.77)
Black	-0.545	-0.465	-0.463	-0.443
	(-1.34)	(-1.22)	(-1.22)	(-1.15)
Other Races	-0.614	-0.407	-0.515	-0.464
	(-0.86)	(-0.61)	(-0.75)	(-0.67)
Native Americans	0.942	0.816	0.817	0.801
	(1.24)	(1.11)	(1.12)	(1.09)
Family Income	0.002	0.002	0.002	0.002
	(0.90)	(1.03)	(0.96)	(0.99)
Education	-0.086	-0.074	-0.071	-0.070
	(-1.81)	(-1.67)	(-1.62)	(-1.57)
Non-participants	-0.341	-0.333	-0.328	-0.368
	(-1.40)	(-1.41)	(-1.39)	(-1.50)
Unemployed	0.087	0.016	0.104	0.216
	(0.12)	(0.02)	(0.15)	(0.32)
Widowed	0.558	0.444	0.470	0.484
	(0.95)	(0.79)	(0.85)	(0.86)
Divorced	0.156	0.014	0.084	0.154
	(0.26)	(0.02)	(0.15)	(0.27)
Single	0.017	0.085	0.123	0.200
	(0.05)	(0.27)	(0.39)	(0.62)
Separated	-0.333	-0.477	-0.499	-0.495
	(-0.45)	(-0.68)	(-0.71)	(-0.70)
N	6569	6569	6569	6569
R^2	0.26	0.27	0.28	0.27
F	132.19	155.87	148.21	145.87

Table 1 (Concluded)

Panel B: Females

Independent Variable	No Assumed Rate	δ=100%	δ=80%	δ=60%
Intercept	-1.346 (-2.04)	-1.360 (-2.10)	-0.973 (-1.58)	-0.371 (-0.63)
Price(t-1)	1.522 (0.25)	---- ----	---- ----	---- ----
Price(t)	-2.638 (-0.36)	0.995 (0.82)	-0.865 (-0.19)	-0.537 (-0.12)
Price(t+1)	2.153 (0.50)	---- ----	1.724 (0.40)	1.269 (0.29)
Lagged Consumption	0.487 (3.39)	0.486 (3.52)	---- ----	---- ----
Future Consumption	0.432 (2.25)	0.440 (2.42)	0.436 (2.40)	0.440 (2.45)
Addictive Stock	---- ----	---- ----	0.386 (3.50)	0.286 (3.52)
Age	0.040 (1.26)	0.037 (1.18)	0.028 (0.88)	0.007 (0.21)
Age Squared	-0.0003 (-0.72)	-0.0002 (-0.62)	-0.0002 (-0.44)	0.00001 (0.03)
Black	0.132 (0.59)	0.152 (0.69)	0.121 (0.55)	0.099 (0.46)
Other Races	0.043 (0.10)	0.113 (0.28)	0.053 (0.12)	0.047 (0.11)
Native Americans	0.083 (0.18)	0.068 (0.14)	0.054 (0.12)	0.009 (0.02)
Family Income	-0.001 (-0.43)	-0.001 (-0.40)	-0.001 (-0.51)	-0.001 (-0.65)
Education	-0.003 (-0.19)	-0.003 (-0.15)	-0.004 (-0.24)	-0.006 (-0.35)
Non-participants	-0.174 (-1.66)	-0.176 (-1.67)	-0.182 (-1.73)	-0.197 (-1.86)
Unemployed	0.691 (0.59)	0.630 (0.55)	0.775 (0.67)	0.875 (0.75)
Widowed	-0.142 (-0.82)	-0.151 (-0.87)	-0.145 (-0.84)	-0.147 (-0.85)
Divorced	-0.329 (-0.97)	-0.362 (-1.10)	-0.312 (-0.95)	-0.288 (-0.87)
Single	0.059 (0.34)	0.061 (0.36)	0.071 (0.42)	0.091 (0.52)
Separated	-0.720 (-2.32)	-0.734 (-2.38)	-0.684 (-2.23)	-0.634 (-2.06)
N	7736	7736	7736	7736
R^2	0.35	0.35	0.35	0.35
F	230.12	258.30	245.55	244.88

a Asymptotic t-ratios are shown in parentheses. The critical asymptotic t-ratios are: 1.28 for a one-tailed test and 1.64 for a two-tailed test at the 10 percent level; 1.64 for a one-tailed test and 1.96 for a two-tailed test at the 5 percent level; and 2.33 for a one-tailed test and 2.58 for a two-tailed test at the 1 percent level. The F statistic for each equation is significant at the 1 percent level.

four lags, current, and four leads of the excise tax on cigarettes. Excise taxes are included in the set of instruments to reduce collinearity problems.

In all models estimated for men, the estimated coefficients for past, current, and future prices, future consumption and past consumption conform to the predictions of the model. Among women, however, the estimates for the coefficients on prices are less consistent with the predictions of the model, while those on past and future consumption are as expected.

In all estimated equations for men, current average cigarette consumption is found to be negatively related to the current price of cigarettes. This relationship is significant with the exception of the models estimated using the addictive stock.[6] Similarly, when included, past and future prices have the anticipated positive effect on current consumption. In the models which include both the lagged and led price of cigarettes, the coefficient on past price is larger in magnitude than the coefficient on future price, as predicted by the model. Similarly, past and future consumption both have positive effects on current consumption. The effect of past consumption is always significant at the one percent level, indicating that cigarette smoking is indeed addictive, as expected. The effect of future consumption on current consumption for men is generally much less significant indicating that men are behaving myopically. As predicted, in the two equations presented containing both past and future consumption, the coefficient on past consumption is larger in magnitude than that on future consumption.

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

The results obtained for women are different in several respects from those obtained for men. In all estimated equations for women, cigarette prices (current, past, and future, when included) do not exhibit a significant impact on average cigarette consumption, indicating that women will not be responsive to changes in cigarette prices arising from the increased excise taxation of cigarettes. However, the estimated coefficients for past and future consumption indicate that women are behaving much less myopically than men. In all estimated equations containing past and future cigarette consumption, a positive relationship is obtained between cigarette consumption in adjacent periods and current cigarette consumption, with almost all estimates significant at the one percent level. Moreover, the ratios of the coefficients on past consumption to the coefficients on future consumption suggest a much lower rate of time preference among women than among men. This may explain the relative insignifance of the money price of cigarettes on the demand for cigarettes among women. If the rate of time preference is low, as discussed earlier, then the shadow price of the addictive stock plays a much larger role in the determination of the full price of smoking. Thus, money prices of cigarettes may be relatively less important than the future health and utility consequences of smoking to women in the calculation of the full price of smoking leading to little or no response as money prices change.

This discussion is supported by the estimates obtained for the income variable. A positive relationship is obtained between income and average cigarette consumption in all equations estimated for men, while the opposite is observed in all equations estimated for women. If cigarettes and health are both normal goods, then an increase in income will have an unclear effect on average cigarette consumption. If an individual has a lower rate of time preference, the effect of income on health (i.e., the individual increases his/her production of health by consuming more medical care and other inputs into health production, and reducing participation in unhealthy activities) may be stronger than the effect of income on current consumption, leading to less cigarette consumption.

An initial examination of the estimates of the exogenous determinants of demand may lead to the conclusion that these variables have little impact on demand. These results, however, may be misleading since the influence of these exogenous variables may be through their effects on future consumption and either lagged consumption or the addictive stock. This possibility is supported by the estimates of comparable ordinary least squares equations where the significance of the exogenous determinants of demand is substantially higher. The qualitative findings, however, are similar across estimation techniques and specifications.

For both males and females, a positive but diminishing relationship is observed between age and average cigarette consumption, with a stronger relationship observed for men. Black men and men of other races are found to smoke less than white men, on average, consistent with observed differences in cigarette smoking among men of different races. Native American men are found to smoke significantly more, in some models, on average than other men. Among women, however, there appear to be no differences in average cigarette consumption attributable to race or ethnicity. Finally, men with more formal education smoke significantly less than those with fewer years of formal education. A much weaker negative relationship is observed between cigarette smoking and education among women.

The marital status and employment status variables were included in an attempt to measure the impact of stressful life-cycle events on cigarette consumption. With respect to employment status, male and female non-participants are found to smoke significantly less than their employed counterparts, with a quantitatively larger relationship found among men. This was anticipated given that the day-to-day work environment is a major determinant of the stress an individual is under. On the other hand, unemployed individuals may be under greater stress leading them to smoke more. These predictions are supported, somewhat, by the positive, though insignificant, coefficients on the unemployment variable for both men and women. The results for the marital status indicators are much less well defined.

Of particular interest in this work is the long run price elasticity of demand for cigarettes. To obtain an estimate of this elasticity, assume that, in the long run, a steady state level of consumption is reached (C^*) which serves to replace depreciation on the addictive stock ($C^* = \delta A^*$, where A^* is the optimal level of the addictive stock). This implies that a permanent change in price will lead to some change in consumption in each period, and, as a result, in the optimal level of the addictive stock, until a new steady state equilibrium is achieved. The resulting long run elasticities are:

$$(13) \quad \frac{\partial C^*}{\partial P} \frac{P}{C^*} = \frac{\beta_1 + \beta_2 + \beta_3}{1 - \beta_4 - \beta_5} \frac{P}{C^*}, \quad \text{from equation (9); and}$$

$$(14) \quad \frac{\partial C^*}{\partial P} \frac{P}{C^*} = \frac{\phi_1 + \phi_2}{1 - \phi_3 - \left[\frac{\phi_4}{\delta}\right]} \frac{P}{C^*}, \quad \text{from equation (10).}$$

Estimates of the long run price elasticities of demand for men, based on the coefficients on cigarette prices, future cigarette consumption, and a measure of past cigarette consumption imply that increased cigarette prices would be an effective means of reducing long run cigarette consumption among men. For men, the long run price elasticity of demand falls in the range from -0.643 to

-0.536, suggesting that an increase in price of 15 percent (the price increase associated with proposals to double the Federal cigarette excise tax rate from 16 cents per pack to 32 cents per pack) would lead to a drop in average cigarette consumption among men of between 8 and 9.6 percent. For women, however, estimates of the long run price elasticity of demand based on the insignificant price estimates suggest that increases in excise taxes would have no impact on cigarette consumption.

A serious problem in the estimation of the various demand equations is the collinearity between cigarette prices and the measures of past and future consumption, possibly resulting in the low statistical significance of the estimated price coefficients. One approach to reducing this problem is to impose the restrictions suggested by the model. In particular, when estimating equation (9), the restriction could be imposed that the coefficients on future price and future consumption be smaller by the factor $1/(1+\sigma)$ than the coefficients on past price and past consumption, respectively. Similarly, when estimating equation (10), the restriction that the coefficient on future price be equal to the coefficient on current price multiplied by the factor $-(1-\delta)/(1+\sigma)$ could be imposed. Table 2 contains estimates of the coefficients on prices, future consumption, and past consumption or the addictive stock, along with the estimated long run price elasticity of demand, when these restrictions are imposed. The results presented as Model 1 impose the restriction that $1/(1+\sigma) = 0.8$,

Table 2[a]
Restricted Two-Stage Least Squares Estimates of Cigarette Demand Equations

Panel A: Men

Independent Variable	No Assumed Rate Model 1	No Assumed Rate Model 2	δ=100% Model 1	δ=100% Model 2
Price(t-1)	7.513	10.459	----	----
	(1.19)	(1.23)	----	----
Price(t)	-17.861	-19.689	-4.538	-5.122
	(-1.57)	(-1.64)	(-2.33)	(-2.55)
Price(t+1)	6.010	4.393	----	----
	(1.19)	(1.23)	----	----
Lagged Consumption	0.441	0.525	0.450	0.542
	(10.29)	(9.73)	(10.76)	(10.44)
Future Consumption	0.353	0.221	0.360	0.227
	(10.29)	(9.73)	(10.76)	(10.44)
Long Run Price Elasticity	-0.608	-0.550	-0.690	-0.641

Independent Variable	δ=80% Model 1	δ=80% Model 2	δ=60% Model 1	δ=60% Model 2
Price(t)	-6.035	-5.552	-7.042	-5.778
	(-2.33)	(-2.32)	(-2.25)	(-2.22)
Price(t+1)	0.966	0.464	2.253	0.959
	(2.33)	(2.32)	(2.25)	(2.22)
Addictive Stock	0.427	0.428	0.312	0.315
	(3.83)	(3.83)	(3.74)	(3.75)
Future Consumption	0.236	0.234	0.263	0.256
	(1.20)	(1.19)	(1.36)	(1.31)
Long Run Price Elasticity	-0.636	-0.633	-0.638	-0.636

Table 2 (concluded)
Restricted Two-Stage Least Squares Estimates
of Cigarette Demand Equations

Panel B: Women

Independent Variable	No Assumed Rate Model 1	No Assumed Rate Model 2	δ=100% Model 1	δ=100% Model 2
Price(t-1)	2.241	2.041	----	----
	(0.56)	(0.55)	----	----
Price(t)	-2.974	-2.827	0.997	0.995
	(-0.42)	(-0.40)	(0.82)	(0.82)
Price(t+1)	1.793	1.837	----	----
	(0.56)	(0.55)	----	----
Lagged Consumption	0.506	0.484	0.510	0.487
	(18.88)	(18.95)	(19.61)	(19.67)
Future Consumption	0.405	0.435	0.408	0.439
	(18.88)	(18.95)	(19.61)	(19.67)
Long Run Price Elasticity	0.559	0.610	0.571	0.631

Independent Variable	δ=80% Model 1	δ=80% Model 2	δ=60% Model 1	δ=60% Model 2
Price(t)	0.987	1.006	0.986	1.025
	(0.68)	(0.68)	(0.56)	(0.55)
Price(t+1)	-0.158	-0.181	-0.315	-0.369
	(-0.68)	(-0.68)	(-0.56)	(-0.55)
Addictive Stock	0.393	0.393	0.291	0.291
	(3.60)	(3.61)	(3.64)	(3.65)
Future Consumption	0.428	0.428	0.432	0.431
	(2.36)	(2.36)	(2.42)	(2.42)
Long Run Price Elasticity	0.482	0.480	0.380	0.367

[a] See note to Table 1.

while those presented as Model 2 use a value for the discount factor suggested by the estimation of the model least subject to the collinearity problems (that imposing a depreciation rate of one hundred percent on the addictive stock).[7] This factor is 0.42 for men and 0.90 for women. Panel A of Table 2 contains the estimated coefficients and associated long run price elasticities of demand for men, with the comparable estimates for women presented in Panel B.

None of the restrictions imposed on the price and/or consumption coefficients has a statistically significant effect, implying that the restrictions are valid. The main result of the imposition of the linear restrictions is that the statistical significance of the price and consumption coefficients is improved in those equations estimated for men, thus improving the estimates of the long run price elasticity of cigarette demand.[8] The estimated price elasticities, however, are almost unchanged. The long run price elasticity of demand for men now falls in the range from -0.55 to -0.69, while that for women remains statistically no different from zero.

VI. CONCLUSIONS

This paper uses cigarette demand equations derived from the Becker-Murphy [1988] model of rational addiction to estimate cigarette demand separately for men and women with data on individuals in the United States. Instrumental variables techniques are used to estimate unrestricted and restricted versions of these demand equations. The focus on differences in the smoking behavior of men and women is important due to the different health risks associated with smoking for the sexes and the observed differences in their response to the anti-smoking campaign of the past 25 years.

In general, the estimates for both men and women support the hypotheses that cigarette smoking is an addictive behavior. Comparing the smoking behavior of men and women, the estimates imply that men are much more responsive to changes in cigarette prices than women, while women behave much less myopically than men. The estimated long run price elasticity of demand for men centers on -0.60, while the estimates obtained suggest that women are virtually unresponsive to changes in the money price of cigarettes.

The estimates presented above lend some support to the hypothesis that increasing the price of cigarettes by increasing excise taxes on cigarettes is an effective policy for reducing smoking, at least among men. A doubling of the Federal excise tax on cigarettes from 16 to 32 cents (as has been proposed as part of a deficit reduction program), resulting in an increase of approximately 15 percent in price (assuming a competitive market) would lead, in the long run, to about an 8 to 10 percent fall in consumption among men. However, this increase would have no significant impact on the cigarette consumption of women.

VII. REFERENCES

Ashton, Heather, and Rob Stepney. Smoking: Psychology and Pharmacology, London: Tavistock Press, 1982.

Atkinson, Anthony B., and Joy L. Skegg. "Anti-Smoking Publicity and the Demand for Tobacco in the U.K." The Manchester School of Economic and Social Studies, 1973, 265-85.

Becker, Gary, and Kevin Murphy. "A Theory of Rational Addiction." Journal of Political Economy, August, 1988, 675-700.

Becker, Gary, Michael Grossman, and Kevin Murphy. "An Empirical Analysis of Cigarette Addiction." Working Paper, University of Chicago, 1988.

Chaloupka, Frank J. "An Economic Analysis of Addictive Behavior: The Case of Cigarette Smoking." Ph.D. dissertation, City University of New York, 1988.

Chaloupka, Frank J. "Rational Addictive Behavior and Cigarette Smoking." Working Paper, University of Illinois at Chicago, 1989.

Fuchs, Victor, Robert Michael, and Sharon Scott. "A State Price Index." Working Paper, National Bureau of Economic Research, 1979.

Mullahy, John. "Cigarette Smoking: Habits, Health Concerns, and Heterogeneous Unobservables in a Microeconometric Analysis of Consumer Demand." Ph.D. Dissertation, University of Virginia, 1985.

Tobacco Tax Council. Municipal Tax Surveys, Richmond, various issues.

Tobacco Tax Council. The Tax Burden on Tobacco, Richmond, 1986.

U.S. Department of Health and Human Services. The Health Consequences of Smoking: for Women, A Report of the Surgeon General, Washington D.C.: Public Health Service, Office on Smoking and Health, 1980.

U.S. Department of Health and Human Services. Smoking and Health: A National Status Report, Washington D.C.: Public Health Service, Centers for Disease Control, 1986.

VIII. ENDNOTES

* Assistant Professor, University of Illinois at Chicago. I'd like to thank Michael Grossman, Gary Becker, Kevin Murphy, John Mullahy, Henry Saffer, participants at the Western Economic Association meetings, and seminar participants at Yale University and the University of Chicago for their helpful comments on earlier drafts of related papers. Any remaining errors, as well as any opinions expressed are the author's. Any comments or suggestions are welcomed.

1. The effects of the stock on current consumption are ambiguous due to the opposing effects of reinforcement and the increase in the shadow price of the stock. Part of the full price of smoking includes the negative effects of the stock on future utility. As the stock increases, the discounted sum of these effects increases, increasing the full price of smoking (through the increase in the shadow price of the stock), and discouraging consumption.

2. Non-addictive models of consumption ignore all future and past effects are ignored. Myopic models of cigarette demand, such as Mullahy's [1985], treat current demand as a function of current price as well as some measure of past consumption and/or prices, but not future consumption and prices. Thus, the estimates allow for the testing of the rational addiction hypothesis. See Chaloupka [1988, 1989] for a more detailed discussion.

3. Alternatively, one could assume that maximum consumption occurs at some arbitrary point in the individual's smoking history, after which it declines at some constant rate (or linearly) until it reaches C(t-1). Based on this assumption, $C^*(t-1)$ could be predicted. However, a mechanical relationship now exists between the dependent variable $C^*(t)$ and the independent variable $C^*(t-1)$ which may result in a spurious relationship between the two.

4. Evidence presented in the Surgeon General's reports suggests that many of the physiological effects of cigarette smoking disappear relatively soon after cessation. Similarly, most of the withdrawal symptoms associated with the cessation of the smoking habit occur relatively soon after stopping, with the only lingering symptom being a craving for nicotine. This suggests that the assumed rate of depreciation should be relatively high.

5. There are two problems associated with the estimation of these demand equations: the endogeneity of past and future consumption and the limited nature of the dependent variables. Relatively more emphasis is placed on the endogeneity problem than on the limited dependent variable problem. In general, doing two stage instrumental variables estimation with this type of limited dependent variable model is quite tricky.

6. All statements concerning the statistical significance of prices, past consumption (or the addictive stock), and future consumption are based on one-tailed tests. When no significance level is indicated, it is assumed to be ten percent.

7. Other values for $1/(1+\sigma)$ were assumed ranging from 0.4 to 0.95 with very little effect on the estimates.

8. Becker, Grossman, and Murphy [1988] derive several other price elasticities of demand based on their version of equation (9). These various elasticities depend on the timing of the price change, whether the change is permanent or temporary, and whether the change is anticipated or unanticipated. Chaloupka [1988] develops comparable elasticities for equation (10). The model predicts the relative magnitudes of these elasticities. When the coefficients on price and/or consumption are estimated in an unrestricted model, mixed support is found for the predictions concerning the relative magnitudes of the various elasticities for men. However, the imposition of the restrictions generally lead to estimated price elasticities in the demand equations for men which conform to all predictions of the model. Due to the complete insignificance of price as a determinant of the demand for cigarettes by women, this discussion is not relevant.

Mathematical Appendix

Following Becker and Murphy (1988) and Becker, Grossman, and Murphy (1988), a quadratic utility function in the three arguments, Y(t), C(t), and A(t) is assumed. The assumption is also made that the individual's rate of time preference is equal to the market rate of interest (that is, σ=r). The resulting instantaneous utility function is:

(A1) $$U(t)= b_Y Y(t) + b_C C(t) + b_A A(t) + \frac{U_{YY}}{2} Y(t)^2 + \frac{U_{CC}}{2} C(t)^2 + \frac{U_{AA}}{2} A(t)^2 + U_{YA} Y(t) A(t) + U_{CA} C(t) A(t) + U_{YC} Y(t) C(t).$$

This implies that the optimal consumption paths are yielded as the solution to:

(A2) $$V^*[\cdot] = \mu R(0) + \underset{CY}{\text{Max}} \left[\int_0^\infty e^{-\sigma t} U(t) - \mu[Y(t) + P_C(t)C(t)]\right]$$

subject to:

(A3) $$\dot{A}(t) = C(t) - \delta A(t), \quad \text{and} \quad A(0)=A_0, \text{ where } \mu \equiv \partial V^*/\partial R(0).$$

Using the first order condition for Y(t), the following substitution can be made:

(A4) $$Y(t) = \frac{1}{U_{YY}} [\mu - b_Y - U_{YA}A(t) - U_{YC}C(t)].$$

Making this substitution results in the maximization problem being a function of only cigarette consumption and the stock of past smoking, or:

(A5) $$V^*[\cdot]= K + \underset{C}{\text{Max}} \left[\int_0^\infty e^{-\sigma t} F[C(t), A(t)]\, dt\right], \text{ where:}$$

(A6) $$F[C(t), A(t)] = \alpha_A A(t) + \alpha_C C(t) + \frac{\alpha_{AA}}{2} A(t)^2 + \frac{\alpha_{CC}}{2} C(t)^2 + \alpha_{CA} C(t) A(t) - \mu P_C(t) C(t),$$

and:

(A7) $$\alpha_A = b_A - \frac{U_{YA}}{U_{YY}} (b_Y - \mu)$$

(A8) $$\alpha_C = b_C - \frac{U_{CA}}{U_{YY}} (b_Y - \mu)$$

(A9) $$\alpha_{AA} = U_{AA} - \frac{U_{YA}^2}{U_{YY}}$$

(A10) $$\alpha_{CC} = U_{CC} - \frac{U_{YC}^2}{U_{YY}}$$

(A11) $$\alpha_{CA} = U_{CA} - \frac{U_{YC}U_{YA}}{U_{YY}}$$

and:

(A12) $$K = \mu R_0 + \left[\frac{(\mu - b_Y^2)}{2\sigma U_{YY}}\right] * \left[1 - \frac{1}{e^{-\sigma t}}\right]$$

where (A5) is maximized subject to (A3) and the transversality condition:

(A13) $$\lim_{t\to\infty} e^{-\sigma t} A(t)^2 = 0.$$

It should be pointed out that α_{AA} and α_{CC} are both negative from the assumption of concavity. Assuming that addictive consumption has no effect on the marginal utility of the composite good Y (U_{CY}=0), then α_{CA}>0.

At this point, to get an empirically tractable demand equation for cigarettes, the model is converted to a discrete time framework.[1] In discrete time, the maximization problem is the following:

(A14) $$V^*[\cdot] = K + \underset{C}{\text{Max}} \left[\Sigma_{t=0}^{\infty}(1+\sigma)^{-t}F[C(t), A(t)]\right]$$

---

[1] Given the specification for the stock accumulation process, C(t) can be replaced with $\delta A(t)/\delta t + \delta A(t)$, making the maximization problem one involving only A(t) and $\delta A(t)/\delta t$. For a complete solution to this problem, and an interesting discussion of the addicts response to changes in various factors over the life cycle, see Becker and Murphy (1988).

where:

(A15) $A(t) = C(t-1) + (1-\delta)A(t-1)$.

A typical first order condition with respect to cigarette consumption for this maximization problem is:

$$\text{(A16)} \quad \frac{\partial V[\cdot]}{\partial C(t)} = \left[\frac{1}{(1+\sigma)^{t}}\right] * \left[\frac{\partial F[C(t),\ A(t)]}{\partial C(t)}\right] +$$

$$\left[\frac{1}{(1+\sigma)^{t+1}}\right] * \left[\frac{\partial F[C(t+1),\ A(t+1)]}{\partial A(t+1)}\right] * \left[\frac{\partial A(t+1)}{\partial C(t)}\right] +$$

$$\left[\frac{1}{(1+\sigma)^{t+2}}\right] * \left[\frac{\partial F[C(t+2),\ A(t+2)]}{\partial A(t+2)}\right] * \left[\frac{\partial A(t+2)}{\partial C(t)}\right] + \ .\ .\ .\ = 0$$

Noting that:

$$\text{(A17)} \quad \frac{\partial F[C(t),\ A(t)]}{\partial C(t)} = \left[\alpha_C + \alpha_{CC}C(t) + \alpha_{CA}A(t)\right] - \mu P_C(t)$$

and:

$$\text{(A18)} \quad \frac{\partial F[C(t),\ A(t)]}{\partial A(t)} = \alpha_A + \alpha_{AA}A(t) + \alpha_{CA}C(t) \quad ,$$

define the term in brackets in equation (A17) as $U_C(t)$ and define the right hand side of equation (A18) as $V_A(t)$. Making these substitutions, equation (A16) can be rewritten as:

$$\text{(A19)} \quad U_C(t) = \mu P_C(t) - \Sigma_{i=1}^{\infty} V_A(t+i) \left[\frac{(1-\delta)^{i-1}}{(1+\sigma)^{i}}\right] .$$

Similar equations can be derived for each time period.

Consider equation (A19) for three time periods: t-1, t, and t+1. In particular, consider:

$$\text{(A20)} \quad \left[\frac{(1-\delta)}{(1+\sigma)}\right] U_C(t) - U_C(t-1) = \mu\left[\frac{(1-\delta)}{(1+\sigma)}\right] P_C(t) - \mu P_C(t-1) + \frac{V_A(t)}{(1+\sigma)}$$

and:

$$\text{(A21)}\quad \left[\frac{(1-\delta)}{(1+\sigma)}\right] U_C(t+1) - U_C(t) = \mu\left[\frac{(1-\delta)}{(1+\sigma)}\right] P_C(t+1) - \mu P_C(t) + \frac{V_A(t+1)}{(1+\sigma)}$$

Using equations (A17)-(A21), the first of the two demand equations (equation (A22) corresponding to equation (9) in the text) is derived. To obtain (A22), multiply equation (A20) by (1-δ) and subtract the resulting equation from (A21). Replace $U_C(i)$ and $V_A(i)$ with their respective definitions given in (A17) and (A18), and solve the remaining equation for C(t).

$$\text{(A22)}\quad C(t) = \beta_0 + \beta_1 P_C(t) + \beta_2 P_C(t-1) + \beta_3 P_C(t+1) + \beta_4 C(t-1) + \beta_5 C(t+1)$$

where:

$$\text{(A23)}\quad \Omega = \left[\frac{2(1-\delta)\alpha_{CA}}{(1+\sigma)} - \frac{\alpha_{AA}}{(1+\sigma)} - \left[\frac{(1-\delta)^2}{(1+\sigma)} + 1\right]\alpha_{CC}\right] > 0$$

$$\text{(A24)}\quad \beta_0 = \frac{1}{\Omega}\left[\delta\alpha_A - \delta\alpha_C\left[\frac{(1-\delta)}{(1+\sigma)} - 1\right]\right]$$

$$\text{(A25)}\quad \beta_1 = \frac{\partial C(t)}{\partial P_C(t)} = -\frac{\mu}{\Omega}\left[1 + \frac{(1-\delta)^2}{(1+\sigma)}\right] < 0$$

$$\text{(A26)}\quad \beta_2 = \frac{\partial C(t)}{\partial P_C(t-1)} = \frac{\mu}{\Omega}(1-\delta) > 0$$

$$\text{(A27)}\quad \beta_3 = \frac{\partial C(t)}{\partial P_C(t+1)} = \frac{\mu}{\Omega}\left[\frac{(1-\delta)}{(1+\sigma)}\right] > 0$$

$$\text{(A28)}\quad \beta_4 = \frac{\partial C(t)}{\partial C(t-1)} = \frac{1}{\Omega}\left[\alpha_{CA} - (1-\delta)\alpha_{CC}\right] > 0$$

$$\text{(A29)}\quad \beta_5 = \frac{\partial C(t)}{\partial C(t+1)} = \frac{1}{\Omega(1+\sigma)}\left[\alpha_{CA} - (1-\delta)\alpha_{CC}\right] > 0 .$$

An alternative demand equation which takes account of the dependence of current consumption on past consumption through the addictive stock can be derived as follows. Using the definitions of the addictive stock, $U_C(t)$, and $V_A(t)$ given above (equations (A15), (A17), and (A18), respectively), reconsider equation (A21). Making the appropriate substitutions, the following demand equation is obtained (corresponding to equation (10) in the text):

$$\text{(A30)}\quad C(t) = \phi_0 + \phi_1 P_C(t) + \phi_2 P_C(t+1) + \phi_3 C(t+1) + \phi_4 A(t) \ ,$$

where:

$$\text{(A31)}\quad \Phi = 1 - \left[\frac{(1-\delta)\alpha_{CA} - \alpha_{AA}}{(1+\sigma)\alpha_{CC}} \right] > 0$$

$$\text{(A32)}\quad \phi_0 = \frac{1}{\Phi} \left[\frac{(1-\delta)\alpha_C - \alpha_A}{(1+\sigma)\alpha_{CC}} - \frac{\alpha_C}{\alpha_{CC}} \right]$$

$$\text{(A33)}\quad \phi_1 = \frac{\partial C(t)}{\partial P_C(t)} = \frac{\mu}{\Phi\alpha_{CC}} < 0$$

$$\text{(A34)}\quad \phi_2 = \frac{\partial C(t)}{\partial P_C(t+1)} = - \frac{\mu}{\Phi\alpha_{CC}} \left[\frac{(1-\delta)}{(1+\sigma)} \right] > 0$$

$$\text{(A35)}\quad \phi_3 = \frac{\partial C(t)}{\partial C(t+1)} = \frac{1}{\Phi} \left[\frac{(1-\delta)\alpha_{CC} - \alpha_{CA}}{(1+\sigma)\alpha_{CC}} \right] > 0$$

$$\text{(A36)}\quad \phi_4 = \frac{\partial C(t)}{\partial A(t)} = \frac{1}{\Phi\alpha_{CC}} \left[\left[\frac{(1-\delta)}{(1+\sigma)} \right] \left[(1-\delta)\alpha_{CA} - \alpha_{AA} \right] - \alpha_{CA} \right] < > 0$$