
Clean indoor air laws, addiction and cigarette smoking

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Cigarette demand equations, derived from the Becker and Murphy (1988) model of rational addiction are estimated which include alternative measures of state level clean indoor air laws. The laws have been the most widely used tool in the recent years of the anti-smoking campaign. Survey data taken from the Second National Health and Nutrition Examination Survey, augmented with county level cigarette prices and excise taxes and state level measures of restrictions on smoking, are used to estimate the demand equations. Clean indoor air laws are found to have a significant negative impact on average cigarette consumption. Increased restrictiveness of these laws, beyond some basic level, however, is not found to further reduce smoking. The effects of these restrictions are found to differ across sexes. Average consumption among men is significantly reduced by the passage of the laws, whereas smoking among women is unaffected. Finally, cigarette prices are found to have a significant negative impact on consumption, with the impact of price limited to men.

I. INTRODUCTION

Every year, cigarette smoking is responsible for 390 000 premature deaths in the United States, approximately 15% of all deaths (USDHHS, 1989), making it the largest single preventable cause of death in the US. In addition, cigarette smoking imposes a significant burden on the US economy.¹ Since 1964, the Federal, state, and local governments have engaged in an active campaign to reduce cigarette smoking. The Federal government was most active early in this campaign, requiring health warning labels to be imposed on all cigarette packaging and advertising, mandating that anti-smoking advertisements be broadcast on television under the Fairness Doctrine, banning all cigarette advertising on television and radio, and disseminating information on the

health consequences of cigarette smoking through the Surgeon General's and other reports.²

State and local governments were less active in the early years of the anti-smoking campaign. During the late 1960s, several states attempted to discourage cigarette smoking by increasing excise tax rates, and thus prices, on cigarettes.³ However, due to the casual and organized smuggling of cigarettes induced by the resulting large differences in cigarette prices, states abandoned increased excise taxation as a means of reducing smoking (Advisory Commission on Intergovernmental Relations, 1977, 1985).

The main policies in the anti-smoking campaign of the past 15 years are direct restrictions on cigarette smoking. These include 'clean indoor air laws' which restrict smoking in a variety of public places and private worksites as well as

¹US Department of Health and Human Services Secretary Louis Sullivan (1990) estimates that smoking costs the US \$52 billion in lost productivity and increased health care costs. This is about \$221 per person, mostly as a result of higher insurance and health care costs. However, a recent study conducted by economists at the RAND Corporation (Manning *et al.*, 1989) concludes that cigarette smokers more than pay their way by subsidizing the Social Security System and other pension plans.

²See the twenty-fifth anniversary edition of the Surgeon General's first report on the health consequences of cigarette smoking for a detailed review of these activities, as well as for an extensive summary of the health consequences (USDHHS, 1989).

³Warner (1981) attributes the large number of state cigarette excise tax increases after the first Surgeon General's report to their attempt to discourage cigarette smoking.

the prohibition of cigarettes sales to minors and in some public places. The Federal government has enacted fairly limited legislation restricting cigarette smoking in two public places: government worksites and transportation facilities.⁴

State and local governments, however, have been very active in this part of the anti-smoking campaign. Early state laws restricting public smoking were enacted with the intent of preventing fires and food contamination. The more recent laws, known as 'clean indoor air laws', are enacted in an attempt to discourage cigarette smoking and are designed to limit the non-smokers exposure to cigarette smoke. These laws, beginning with that of Arizona in 1973, are the result of pressure from various non-smokers' rights organizations and of recent research concerning the effects of cigarette smoke on the health of non-smokers.⁵ The health link, first suggested by the Surgeon General in 1972, was firmly established in his 1986 *Report on the Health Consequences of Involuntary Smoking*. The major conclusion of this report is that cigarette smoke presents a greater health hazard to non-smokers than do all other air pollutants combined. The Surgeon General also concludes that exposure to cigarette smoke can cause lung cancer in otherwise healthy non-smokers. Finally, the report also concludes the simple separation of smokers and non-smokers within the same air space may lower, but will not eliminate, the hazards of exposure to environmental tobacco smoke.

Clean indoor air laws generally prohibit cigarette smoking in health care facilities, retail stores, public transportation, indoor cultural or recreational facilities, government buildings, public meeting rooms and schools. Many laws, beginning with Connecticut in 1974, also restrict smoking in restaurants, usually requiring separate non-smoking sections. Finally, the most restrictive versions of these laws, starting with Minnesota in 1975, regulate cigarette smoking at private worksites. Currently, almost every state has some restriction on public place smoking, with 23 states restricting smoking in restaurants, and 13 states regulating smoking at private worksites. In addition, several hundred localities have enacted additional restrictions on smoking during the 1980s (USDHHS, 1989).

Although many states and localities have already enacted clean indoor air laws and numerous others are considering extending or enacting these laws, little is known about their impact on cigarette smoking. The impact of these laws on cigarette demand is examined, using demand equations derived from the Becker and Murphy (1988) model of rational

addictive behaviour. Data taken from a large national survey, the Second National Health and Nutrition Examination Survey (NHANES2), augmented with cigarette prices, excise taxes and indicators of state level restrictions, will be used to estimate these demand equations. Chaloupka and Saffer (forthcoming) use a time-series of state cross sections to address the issue of the potential endogeneity of these laws, concluding that less restrictive laws have a significant negative impact on demand, but that the most restrictive laws were enacted in states where smoking was low initially. However, there have been no published or unpublished studies about the impact of these laws on individuals' cigarette smoking in the context of addiction.⁶

II. ANALYTICAL FRAMEWORK

This work uses the Becker–Murphy model of rational addictive behaviour to model cigarette smoking. In this model, tastes are constant and the individual is assumed to be rational in the sense that the future consequences of current and past behaviour are taken into consideration in the utility maximization process. This is in contrast to other economic models of habitual or addictive behaviour which treat addicts as having endogenous tastes and/or behaving myopically.

The distinction between addictive consumption and other consumption is captured by recognizing that, for addictive goods, current consumption depends on the level of past consumption. This time dependence of consumption incorporates the notions of acquired tolerance, reinforcement, and withdrawal characteristic of addictive consumption (Donegan *et al.*, 1983; Peele, 1985). Tolerance suggests that a given level of consumption leads to less satisfaction as past consumption of the addictive good is higher. Reinforcement implies a learned response to past consumption, and can be positive or negative. Finally, withdrawal refers to a negative physical reaction and other reductions in utility associated with the cessation of consumption.

The addictive model is appropriate for analysing the demand for cigarettes since, according to the Surgeon General, the processes leading to tobacco addiction are similar to those determining addictions to illegal drugs such as heroin and cocaine (USDHHS, 1988).⁷

Following Becker and Murphy, an individual's utility at a moment in time is assumed to depend on three factors: current cigarette consumption, $C(t)$, the depreciated sum or

⁴The most recent extension of these restrictions prohibits cigarette smoking on almost all domestic flights, effective from 25 February 1990.

⁵That this is the intent of these laws can be seen from the phrases introducing the legislation. For example, the Alaska law begins 'Smoking is declared a nuisance and a public health hazard'. Similarly, the Minnesota and Nevada laws are enacted 'for the purpose of protecting public health, comfort, and environment by prohibiting smoking in public places' (USDHHS, 1986b).

⁶Of course, there is an extensive literature which looks at the impact on the demand for cigarettes of cigarette prices and the various policies of the anti-smoking campaign. See Chaloupka (1988) and the 1989 Surgeon General's Report for detailed reviews of this literature.

⁷See Chaloupka (1988, 1991) for a detailed discussion of cigarette smoking in the context of the Becker–Murphy model of rational addictive behaviour.

'addictive stock' of all past cigarette consumption, $A(t)$, and a vector of other goods and services providing utility, $Y(t)$. This utility function is maximized over the individual's lifetime (assumed infinite), subject to an appropriate budget constraint, a stock accumulation equation, and an initial stock condition. Assuming a quadratic utility function in these three arguments, the following instantaneous utility function is obtained:

$$U(t) = b_Y Y(t) + b_C C(t) + b_A A(t) + \frac{U_{YY}}{2} Y(t)^2 + \frac{U_{CC}}{2} C(t)^2 + \frac{U_{AA}}{2} A(t)^2 + U_{YA} Y(t)A(t) + U_{CA} C(t)A(t) + U_{YC} Y(t)C(t) \quad (1)$$

Assuming that the individual's rate of time preference is equal to the market rate of interest, 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 (see the mathematical appendix for a detailed derivation of both demand equations):⁸

$$C(t) = \beta_0 + \beta_1 P_C(t) + \beta_2 P_C(t-1) + \beta_3 P_C(t+1) + \beta_4 C(t-1) + \beta_5 C(t+1) \quad (2)$$

and

$$C(t) = \phi_0 + \phi_1 P_C(t) + \phi_2 P_C(t+1) + \phi_3 C(t+1) + \phi_4 A(t) \quad (3)$$

In both demand equations, current consumption is predicted to be negatively related to the current price of cigarettes, $P_C(t)$, but positively related to both past (when included) and future prices, $P_C(t-1)$ and $P_C(t+1)$, respectively, when past and future cigarette consumption is held constant. In the context of the Becker–Murphy model, addiction implies that cigarette consumption in different time

periods are complements. Thus, current cigarette consumption, if the good is addictive, is expected to be positively related to future cigarette consumption. Similarly, when lagged cigarette consumption is included, current consumption is predicted to be positively related to lagged consumption. However, when the stock of all past cigarette consumption enters, no prediction can be made concerning the direction of the relationship between it and current cigarette consumption.⁹ Finally, these demand equations hold the marginal utility of wealth constant.¹⁰

Since clean indoor air laws impose difficulties or costs on individuals who wish to smoke, variables indicating the presence and degree of restrictiveness of clean indoor air laws can be included in these demand equations as measures of the full price of cigarettes.¹¹ One potential problem with including these laws in cigarette demand equations is that the clean indoor air laws may be endogenous. While this may present a problem when estimating cigarette demand using aggregate data, this should not hamper the estimation of cigarette demand equations using individual data.¹²

III. 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 aged 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 oversampled. Each individual age 18 years and older completed detailed questionnaires on their health histories and most underwent a comprehensive physical examination. Data on dietary patterns, including alcohol and cigarette consumption, were also collected.

Based on an individual's state of residence, the following set of indicators of clean indoor air laws is added to the data

⁸The first of these equations provides a more direct test of the addictive model but is difficult to estimate due to the collinearity among lagged, current and led cigarette prices. The second, which replaces past cigarette price and consumption with the cumulative stock of past consumption provides a less direct test, but is computationally easier.

⁹The 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, due to the effects of tolerance and the negative health consequences of cigarette smoking. 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.

¹⁰Non-addictive models of consumption ignore all future and past price and consumption effects. Myopic models of cigarette demand (e.g. Mullahy, 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 price. Thus, the estimation of these demand equations allows for the testing of the rational addiction hypothesis. See Chaloupka (1988, 1991) for a more detailed discussion.

¹¹Ideally, measures of these laws would be included in the same way that cigarette prices are included. However, this cannot be done using the NHANES2 data since there is almost no intrastate variation in these laws over the short time period (1976–1980) covered by the data. The source of the variation in the laws is due to interstate variation in the presence and restrictiveness of the laws.

¹²The presence of clean indoor air laws is expected to be more closely related to average statewide cigarette consumption than to smoking by a given individual in the state. Thus, the laws may be endogenous at the aggregate level, but are likely to be exogenous at the individual level. See Chaloupka and Saffer (forthcoming) for an examination of the potential endogeneity of clean indoor air laws which estimates cigarette demand using state aggregates. They find that 'moderate' laws have a significant independent negative effect on cigarette sales, 'extensive' laws have only been enacted in states where smoking is low to begin with and, thus, have no independent effect on cigarette sales.

set. This set of indicators is based on the classification scheme presented in various reports of the Surgeon General (USDHHS, 1986a, 1989). The Surgeon General classifies laws as follows: a state has 'nominal' restrictions on cigarette smoking if it limits smoking in one to three public places excluding restaurants and private worksites; 'basic' restrictions if it regulates smoking in four or more public places excluding restaurants and private worksites; 'moderate' restrictions if it regulates smoking in restaurants but not in private worksites; and 'extensive' restrictions if it regulates smoking in private worksites. A set of dichotomous indicators for laws at each of these four levels of restrictiveness is included to estimate the anticipated non-linear impact of increased restrictiveness on cigarette smoking. If a state has no restrictions, all indicators are zero.

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 20 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. Failure 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 25 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 (1985) based on the procedure described by Fuchs *et al.* (1979).¹³

To estimate demand Equation 2, 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 2. 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 $C^*(t-1)$.¹⁴ 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-quarter of the sample), maximum consumption is used as a proxy for $C^*(t-1)$.¹⁵

To estimate demand Equation 3, current and future consumption and a measure of the addictive stock are required. Current and future consumption are obtained as described above. Assuming a simple investment function for the addictive stock

$$A(t) = C(t-1) + (1-\delta)A(t-1) \quad (4)$$

where δ is the depreciation rate for the addictive stock, and that the initial stock is zero, the stock at time t is

$$A(t) = \sum_{i=0}^{t-1} (1-\delta)^{t-1-i} C(i) \quad (5)$$

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

$$\begin{aligned} A(t) &= \sum_{i=0}^{t-1} D(i)C(i) = t\bar{D}\bar{C} + t \text{Cov}[D(i), C(i)] \\ &= \bar{C} \left[\frac{1-(1-\delta)^t}{\delta} \right] + t \text{Cov}[D(i), C(i)] \end{aligned} \quad (6)$$

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

The covariance term in Equation 6 is assumed to be relatively small and is ignored. 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.

¹³A second potential endogeneity problem is that heavier smokers may purchase cigarettes in cartons (lowest price form) rather than in single packs or through vending machines. Given available data, nothing can be done about this problem.

¹⁴ $C^*(t-1)$ is actually an estimate of cigarette consumption two years prior to the individual's interview during NHANES2.

¹⁵Alternatively, 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.

One other potential problem with these data is that individuals may report the same consumption for all three periods, given the tendency to report in fractions of packs consumed. Of the 5111 current smokers in the data set, approximately 44% report the same current, lagged, and maximum consumption. This is an additional reason for estimating Equation 3, the demand equation including the stock of cumulative past consumption.

For smokers, maximum consumption is used as a proxy for mean consumption, with a modified version of Equation 6 used to compute the stock for former smokers. Various depreciation rates are assumed and the sensitivity of the results to these rates is shown below.¹⁶ Finally, all clean indoor air law, cigarette price and cigarette excise tax variables are adjusted appropriately when either demand equation is estimated.

Brief definitions, means, and standard deviations of these variables are contained in Table 1. Column A presents the

descriptive statistics for the full sample, while Column B presents those for the sample of ever smokers.¹⁷

In each equation, the individual's age, age squared, race, real family income, and a measure of educational attainment are included as independent variables. Finally, each equation also includes indicators of marital status and labour force status in an attempt to capture the effects of stressful life-cycle events, such as divorce, separation, and unemployment, on cigarette smoking.¹⁸

Finally, the estimated long-run price elasticity of demand

Table 1. Definitions and descriptive statistics

Variable	Definition	Column A Full sample	Column B Ever smokers
Nominal clean indoor air law	Dichotomous indicator of law restricting cigarette smoking in 1 to 3 public places excluding restaurants and private worksites	$\mu = 0.268$ $\sigma = 0.443$	$\mu = 0.267$ $\sigma = 0.443$
Basic clean indoor air law	Dichotomous indicator of law restricting cigarette smoking in 4 or more public places excluding restaurants and private worksites	$\mu = 0.208$ $\sigma = 0.406$	$\mu = 0.208$ $\sigma = 0.406$
Moderate clean indoor air law	Dichotomous indicator of law restricting cigarette smoking in restaurants but not at private worksites	$\mu = 0.073$ $\sigma = 0.261$	$\mu = 0.074$ $\sigma = 0.262$
Extensive clean indoor air law	Dichotomous indicator of law restricting cigarette smoking in private worksites	$\mu = 0.024$ $\sigma = 0.153$	$\mu = 0.023$ $\sigma = 0.150$
Current cigarette consumption	Average daily cigarette consumption	$\mu = 7.811$ $\sigma = 13.065$	$\mu = 14.062$ $\sigma = 14.812$
Past cigarette consumption	One year lag of average daily cigarette consumption	$\mu = 10.158$ $\sigma = 15.965$	$\mu = 18.286$ $\sigma = 17.614$
Future cigarette consumption	One year lead of average daily cigarette consumption	$\mu = 7.196$ $\sigma = 12.241$	$\mu = 12.954$ $\sigma = 13.970$
Addictive stock, $\delta = 80\%$	Estimated stock of cumulative past cigarette consumption assuming a depreciation rate of 80%	$\mu = 12.723$ $\sigma = 19.846$	$\mu = 22.905$ $\sigma = 21.814$
Addictive stock, $\delta = 60\%$	Estimated stock of cumulative past cigarette consumption assuming a depreciation rate of 60%	$\mu = 16.999$ $\sigma = 26.271$	$\mu = 30.602$ $\sigma = 28.744$
Current cigarette price	Equally weighted average price, in dollars, per pack of 20 cigarettes in the county in which the individual resides and the lowest price within 25 miles of the county of residence, deflated by the National Consumer Price Index and a state-specific price index	$\mu = 0.285$ $\sigma = 0.038$	$\mu = 0.285$ $\sigma = 0.038$
Past cigarette price	One year lag of cigarette price	$\mu = 0.286$ $\sigma = 0.038$	$\mu = 0.287$ $\sigma = 0.038$
Future cigarette price	One year lead of cigarette price	$\mu = 0.279$ $\sigma = 0.040$	$\mu = 0.279$ $\sigma = 0.040$

μ and σ denote the sample mean and standard deviation, respectively. The full sample contains 14 305 observations while the sample of ever smokers contains 7946 observations. The lifetime smoking participation rate in the full sample is 55.6%. The current participation rate in the full sample is 35.7%. Finally, the current participation rate among ever smokers is 64.3%.

¹⁶Evidence 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.

¹⁷Ever smokers refers to current and former smokers. Former smokers, given the importance of cumulative past consumption in the addictive model, should be included when limiting the sample to smokers only.

¹⁸An appendix, available on request, contains a detailed description of these variables, their descriptive statistics, and the estimates obtained for each.

for cigarettes obtained from this model is of some interest. To estimate 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:

$$\frac{\partial C^*}{\partial P} \frac{P}{C^*} = \frac{\beta_1 + \beta_2 + \beta_3}{1 - \beta_4 - \beta_5} \frac{P}{C^*} \quad (7)$$

from Equation 2 and:

$$\frac{\partial C^*}{\partial P} \frac{P}{C^*} = \frac{\phi_1 + \phi_2}{1 - \phi_3 - [\phi_4/\delta]} \frac{P}{C^*} \quad (8)$$

from Equation 3.

IV. RESULTS

Introduction

Estimates of demand Equations 2 and 3 are reported in Table 2. Panel A of Table 2 presents the estimates for the full sample, whereas Panel B presents estimates for the sample of ever smokers. Column 1 of Table 2 contains the estimates of Equation 2 where no assumption is made about the rate of depreciation on the addictive stock. Column 2 contains the estimates of Equation 2 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 3 assuming rates of depreciation of 80 and 60% 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 2, and the addictive stock and future consumption in Equation 3.¹⁹ In Equation 2, 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 3. Thus, the set of instruments employed includes the exogenous variables affecting consumption, four lags of price, current price, and four leads of price, and four lags, current, and four leads of the excise tax on cigarettes.²⁰

A serious problem in estimating the alternative cigarette demand equations is the collinearity between past, current and future prices and the measures of past and future consumption. While the parameter estimates in the presence of collinearity are unbiased, their statistical significance will be lowered. One approach to reducing this problem is to impose the restrictions suggested by the model. In particular, when estimating Equation 2, 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 3, 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 3 contains estimates comparable to those presented in Table 2 when the restriction that $1/(1+\sigma)=0.95$ is imposed.²¹

Discussion

All results generally conform to *a priori* expectations. Estimates for the clean indoor air laws show that the laws have a statistically significant negative impact on the demand for cigarettes.²² However, only the indicators of 'basic' and 'moderate' laws are found to be individually statistically significant in most models.²³ Furthermore, the coefficients on these two indicators are generally not statistically different from one another. These patterns are observed in both the unrestricted and restricted versions of the estimates for the full sample and the sample of ever smokers.

¹⁹There 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. Given the theoretical model, emphasis is placed on the endogeneity problem than on the limited dependent variable problem. Taking account of both the endogeneity and the limited dependent variable is intractable. Finally, the use of instrumental variables for the alternative measures of lagged consumption will alleviate the measurement error problems associated with these variables. As an anonymous referee points out, limiting the sample to smokers is a pragmatic solution to the limited dependent variables problem.

²⁰The lagged, current, and led excise tax rates are included in the set of instruments to attempt to reduce the collinearity problems faced in the estimation of the various demand equations.

²¹This value is obtained from the ratio of future consumption to past consumption in the model which imposes a 100% rate of depreciation on the addictive stock. Imposing these restrictions did not have a statistically significant impact on the residual sum of squares implying that the restrictions are valid. Other values ranging from 0.70 to 0.99 were also imposed. There were no substantive changes in the results using these other values. These results are available on request.

²²This conclusion is based on an F-test which tests the hypothesis that the coefficients on all four indicators are simultaneously equal to zero.

²³The insignificant results for the extensive restrictions indicator may be due to the very small number of individuals (about 2.4% of the sample) living in states with this type of clean indoor air law.

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Table 2. Two-stage least squares estimates of cigarette demand equations

Independent variable	No assumed rate	$\delta = 100\%$	$\delta = 80\%$	$\delta = 60\%$
<i>A: Full sample</i>				
Nominal	-0.133 (-1.18)	-0.069 (-0.66)	-0.125 (-1.14)	-0.139 (-1.25)
Basic	-0.265 (-2.25)	-0.268 (-2.33)	-0.272 (-2.33)	-0.302 (-2.53)
Moderate	-0.324 (-1.58)	-0.172 (-0.99)	0.362 (-1.76)	-0.419 (-1.98)
Extensive	-0.159 (-0.55)	-0.161 (-0.56)	-0.168 (-0.58)	-0.176 (-0.60)
Price ($t-1$)	5.381 (0.91)	—	—	—
Price (t)	-13.235 (-1.75)	-1.208 (-1.02)	-7.797 (-1.55)	-7.797 (-1.55)
Price ($t+1$)	6.574 (1.36)	—	6.648 (1.39)	6.445 (1.33)
Lagged consumption	0.465 (3.24)	0.443 (3.26)	—	—
Future consumption	0.361 (1.81)	0.415 (2.26)	0.413 (2.24)	0.397 (2.15)
Addictive stock	—	—	0.349 (3.20)	0.270 (3.29)
LR elasticity	-0.268	-0.310	-0.278	-0.322
R^2	0.3556	0.3601	0.3585	0.3542
F	344.150	384.354	364.369	357.541
<i>B: Ever smokers</i>				
Nominal	-0.225 (-1.13)	-0.122 (-0.65)	-0.213 (-1.09)	-0.240 (-1.21)
Basic	-0.481 (-2.25)	-0.484 (-2.33)	-0.487 (-2.32)	-0.540 (-2.52)
Moderate	-0.580 (-1.61)	-0.324 (-1.04)	-0.644 (-1.78)	-0.749 (-2.00)
Extensive	-0.244 (-0.46)	-0.256 (-0.48)	-0.251 (-0.48)	-0.269 (-0.51)
Price ($t-1$)	8.791 (0.81)	—	—	—
Price (t)	-22.527 (-1.65)	-2.351 (-1.09)	-14.007 (-1.58)	-13.642 (-1.52)
Price ($t+1$)	11.141 (0.81)	—	11.388 (1.34)	10.958 (1.27)
Lagged consumption	0.461 (3.06)	0.444 (3.01)	—	—
Future consumption	0.386 (1.94)	0.439 (2.42)	0.430 (2.34)	0.402 (2.16)
Addictive stock	—	—	0.360 (3.07)	0.282 (3.19)
LR elasticity	-0.344	-0.407	-0.442	-0.425
R^2	0.2529	0.2548	0.2543	0.2503
F	117.927	130.376	124.175	121.602

Notes: 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% level; 1.64 for a one-tailed test and 1.96 for a two-tailed test at the 5% level; and 2.33 for a one-tailed test and 2.58 for a two-tailed test at the 1% level. The F statistic for each equation is significant at the 1% level. $n = 14\,305$ for the full sample and 7946 for the sample of ever smokers. Each equation also includes individual's age, age squared, the number of years of formal education completed, real family income, and indicators of sex, race and ethnicity, marital status, and labour force status. Results for these variables are available on request.

Table 3. Restricted two-stage least squares estimates of cigarette demand equations

Independent variable	No assumed rate	$\delta = 100\%$	$\delta = 80\%$	$\delta = 60\%$
<i>A: Full sample</i>				
Nominal	-0.127 (-1.15)	-0.069 (-0.66)	-0.082 (-0.78)	-0.104 (-0.97)
Basic	-0.264 (-2.30)	-0.268 (-2.35)	-0.289 (-2.48)	-0.318 (-2.68)
Moderate	-0.293 (-1.59)	-0.171 (-1.02)	-0.229 (-1.28)	-0.308 (-1.63)
Extensive	-0.177 (-0.63)	-0.162 (-0.58)	-0.160 (-0.54)	-0.161 (-0.55)
Price ($t-1$)	6.055 (1.64)	—	—	—
Price (t)	-12.961 (-1.79)	-1.200 (-1.06)	-1.687 (-1.14)	-2.434 (-1.26)
Price ($t+1$)	5.752 (1.64)	—	0.320 (1.14)	0.925 (1.26)
Lagged consumption	0.430 (16.81)	0.440 (17.97)	—	—
Future consumption	0.408 (16.81)	0.418 (17.97)	0.396 (2.15)	0.374 (2.03)
Addictive stock	—	—	0.364 (3.36)	0.283 (3.48)
LR elasticity	-0.319	-0.308	-0.335	-0.357
R^2	0.3577	0.3603	0.3586	0.3533
F	380.291	403.784	381.826	373.145
<i>B: Ever smokers</i>				
Nominal	-0.219 (-1.11)	-0.122 (-0.65)	-0.146 (-0.78)	-0.187 (-0.97)
Basic	-0.486 (-2.34)	-0.485 (-2.34)	-0.518 (-2.48)	-0.568 (-2.67)
Moderate	-0.539 (-1.63)	-0.329 (-1.09)	-0.426 (-1.33)	-0.572 (-1.70)
Extensive	-0.270 (-0.52)	-0.249 (-0.48)	-0.249 (-0.47)	-0.259 (-0.49)
Price ($t-1$)	10.254 (1.56)	—	—	—
Price (t)	-22.455 (-1.73)	-2.386 (-1.15)	-3.291 (-1.22)	-4.771 (-1.35)
Price ($t+1$)	9.741 (1.56)	—	0.652 (1.22)	1.813 (1.35)
Lagged consumption	0.434 (8.79)	0.452 (9.42)	—	—
Future consumption	0.413 (8.79)	0.429 (9.42)	0.414 (2.26)	0.380 (2.05)
Addictive stock	—	—	0.367 (3.12)	0.289 (3.28)
LR elasticity	-0.326	-0.406	-0.420	-0.433
R^2	0.2535	0.2548	0.2538	0.2491
F	129.496	136.804	129.703	126.507

See notes to Table 1.

These results imply that, beyond some point, the degree of restrictiveness of the law is not what is affecting cigarette demand. If the law's impact on smoking comes from limiting the smoker's opportunity to smoke, then more restrictive laws (those restricting smoking in more places) should have

a greater impact on average cigarette consumption than less restrictive laws. The only apparent differences in the impact of restrictiveness on demand are found between nominal restrictions and basic restrictions, as well as between no restrictions and any restrictions. Further reductions in

smoking are not observed as restrictiveness is increased from the 'basic' level to the 'moderate' level. One unmeasured factor which may be being captured by the law indicators is publicity on the negative health consequences of cigarette smoking which accompanies the passage of a clean indoor air law. Although the restrictiveness of the laws being enacted may vary, the publicity accompanying the passage of the law is most probably independent of the degree of restrictiveness of the law. Increasing the restrictiveness of clean indoor air laws appears to have little impact on demand, beyond some point. However, increasing awareness of the health consequences of cigarette smoking through information campaigns may be an effective means of reducing smoking.

Turning to the other variables of interest, the estimates for cigarette prices and past and future consumption generally conform to the predictions of the theoretical model of rational addiction. Current cigarette price is always found to have a negative and, in most models, statistically significant impact on average cigarette consumption.²⁴ Past (when included) and future prices generally have a statistically significant positive effect on demand, holding past and future consumption constant, as anticipated. Similarly, future consumption and the measure of past consumption employed both have a significant positive impact on current cigarette consumption. Imposing the restrictions on the estimates implied by the theoretical model generally improves the statistical significance of past and future cigarette prices. Similarly, past and future cigarette consumption are more significant when the restrictions are imposed.

The significant past price and consumption effects confirm the expectation that cigarette smoking is an addictive behaviour, whereas the significant future price and consumption effects support the hypothesis that individuals are not behaving myopically.

Estimated long-run price elasticities of demand are in the range -0.27 to -0.36 for the full sample and -0.33 to -0.44 for the sample of ever smokers. These estimates imply that the recent doubling of the Federal excise tax on cigarettes will be effective in reducing cigarette consumption, with average consumption falling approximately 4–6% as a result of the 15% increase in average cigarette prices. This impact may be larger if the increase in the excise tax results in a greater increase in cigarette prices. Harris (1987) suggests that cigarette manufacturers used the 1983 doubling of the Federal excise tax as a co-ordinating mechanism for an oligopolistic price increase. He estimates that cigarette prices increased 16 cents per pack as a result of the eight cent increase in the Federal excise tax. If similar non-tax price increases occur, demand could fall as much as 12%.

²⁴Statement concerning the statistical significance of the price and consumption coefficients are based on one-tailed tests, given the predictions of the model. When no significance level is indicated, it is assumed to be at the 10% level.

²⁵Estimates for male and female samples limited to ever smokers as well as restricted estimates were not qualitatively different from those presented below. These estimates are available on request.

V. MEN, WOMEN AND CLEAN INDOOR AIR LAWS

Over the past 25 years, the anti-smoking campaign has significantly reduced both smoking participation rates and average cigarette consumption. However, these reductions have not occurred uniformly. Most dramatic are the differences in cigarette smoking patterns observed between men and women. While smoking participation rates among men fell almost 20 percentage points from 52.9% in 1964 to 33% in 1986, participation rates among women have fallen only 6 points from a high of 34.1% in 1965 to 28% in 1986. Similarly, fewer men are initiating smoking in recent years than at any other time this century, whereas smoking initiation rates among women have remained fairly steady since 1970, with participation rates actually increasing among young women (USDHHS, 1986b). Given these trends, differences in the impact of clean indoor air laws on cigarette demand for men and women were explored by estimating separate demand equations for men and women. Estimates for men are contained in Panel A of Table 4, and those for women are in Panel B.²⁵

The results for men and women show dramatic differences in their response to both clean indoor air laws and cigarette prices. Men in states with clean indoor air laws are found to smoke significantly less, on average, than their counterparts in states with no restrictions on smoking. As in the full sample, increased restrictiveness, up to some point, leads to less smoking among men. Further restrictions, however, appear to have no impact on demand. The smoking behaviour of women, however, is found to be virtually unaffected by restrictions on cigarette smoking. Neither the set of dichotomous indicators, nor any single clean indoor air law has any statistically significant effect on average cigarette consumption among women.

Similarly, increased cigarette prices are found significantly to lower average cigarette consumption among men whereas cigarette prices have no impact on smoking among women. The long-run price elasticity of demand obtained for men centres on -0.49 . That obtained for women is not statistically different from zero.

VI. CONCLUSIONS

Demand equations, derived from the Becker–Murphy model of rational addictive behaviour are estimated which include alternative measures of state level clean indoor air laws. These laws have become the most widely used tool of state and local governments in the recent years of the anti-smoking campaign. Estimates obtained using the full

Table 4. Two-stage least squares estimates of cigarette demand equations

Independent variable	No assumed rate	$\delta=100\%$	$\delta=80\%$	$\delta=60\%$
<i>A: Men</i>				
Nominal	-0.375 (-1.75)	-0.263 (-1.34)	-0.338 (-1.64)	-0.336 (-1.62)
Basic	-0.712 (-2.89)	-0.686 (-2.90)	-0.672 (-2.84)	-0.686 (-2.89)
Moderate	-0.713 (-1.92)	-0.511 (-1.63)	0.766 (-2.13)	-0.827 (-2.29)
Extensive	-0.473 (-0.80)	-0.438 (-0.76)	-0.468 (-0.81)	-0.431 (-0.74)
Price ($t-1$)	11.869 (1.12)	—	—	—
Price (t)	-24.789 (-1.87)	-4.073 (-1.79)	-13.819 (-1.55)	-13.537 (-1.50)
Price ($t+1$)	9.004 (1.01)	—	9.838 (1.13)	9.624 (1.09)
Lagged consumption	0.410 (2.49)	0.429 (2.72)	—	—
Future consumption	0.324 (1.45)	0.333 (1.61)	0.370 (1.74)	0.353 (1.65)
Addictive stock	—	—	0.322 (2.51)	0.252 (2.58)
LR elasticity	-0.425	-0.494	-0.505	-0.497
R^2	0.28	0.29	0.29	0.28
F	114.82	131.26	125.06	122.57
<i>B: Women</i>				
Nominal	0.061 (0.48)	0.059 (0.49)	0.048 (0.17)	0.027 (0.21)
Basic	-0.015 (-0.11)	-0.015 (-0.11)	-0.038 (-0.28)	-0.069 (-0.49)
Moderate	0.089 (0.36)	0.086 (0.42)	0.057 (0.23)	0.020 (0.08)
Extensive	0.160 (0.50)	0.158 (0.49)	0.137 (0.43)	0.098 (0.30)
Price ($t-1$)	-0.362 (-0.06)	—	—	—
Price (t)	1.290 (0.15)	0.826 (0.66)	0.967 (0.17)	1.014 (0.18)
Price ($t+1$)	-0.112 (-0.02)	—	-0.225 (-0.04)	-0.360 (-0.06)
Lagged consumption	0.368 (2.74)	0.370 (2.82)	—	—
Future consumption	0.596 (3.40)	0.593 (3.54)	0.579 (3.36)	0.565 (3.20)
Addictive stock	—	—	0.303 (2.85)	0.234 (2.86)
LR elasticity	1.322	1.410	1.046	0.852
R^2	0.31	0.31	0.31	0.31
F	211.78	242.56	228.76	229.62

See Notes to Table 2. The number of observations is 6569 for men and 7736 for women.

sample of adults taken from the Second National Health and Nutrition Examination Survey show that the passage of a clean indoor air law does have a negative impact on average cigarette consumption. However, the results suggest that increasing the restrictiveness of these laws, beyond some 'basic' level, does not appear to have a greater impact on cigarette consumption.

Estimates obtained from demand equations estimated separately for men and women imply that the impact of the clean indoor air laws is found primarily among men. Cigarette smoking among women is not affected by either the presence or the restrictiveness of a clean indoor air law.

Finally, increased cigarette prices, which would result from increased cigarette excise taxes, are also found to have

a significant negative impact on average cigarette consumption. As with smoking restrictions, prices appear to affect the smoking behaviour of men while having no impact on the smoking behaviour of women.

VII. MATHEMATICAL APPENDIX

Following Becker and Murphy (1988) and Becker *et al.* (1990), 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, $\sigma = r$). The resulting instantaneous utility function is

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

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

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

subject to

$$\dot{A}(t) = C(t) - \delta A(t) \quad A(0) = A_0 \quad (A3)$$

where $\mu \equiv \partial V^* / \partial R(0)$.

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

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

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

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

where

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

and

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

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

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

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

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

and

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

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

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

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 ($U_{CY} = 0$), then $\alpha_{CA} > 0$.

At this point, to get an empirically tractable demand equation for cigarettes, the model is converted into a discrete time framework.²⁶ In discrete time, the maximization problem is as follows:

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

where

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

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

$$\begin{aligned} \frac{\partial V[\cdot]}{\partial C(t)} &= \left[\frac{1}{(1 + \sigma)^t} \right] * \left[\frac{\partial F[C(t), A(t)]}{\partial C(t)} \right] + \left[\frac{1}{(1 + \sigma)^{t+1}} \right] \\ &* \left[\frac{\partial F[C(t+1), A(t+1)]}{\partial A(t+1)} \right] * \left[\frac{\partial A(t+1)}{\partial C(t)} \right] \\ &+ \left[\frac{1}{(1 + \sigma)^{t+2}} \right] * \left[\frac{\partial F[C(t+2), A(t+2)]}{\partial A(t+2)} \right] \\ &* \left[\frac{\partial A(t+2)}{\partial C(t)} \right] + \dots = 0 \end{aligned} \quad (A16)$$

²⁶ Given the specification for the stock accumulation process, $C(t)$ can be replaced with $\partial A(t) / \partial t + \delta A(t)$, making the maximization problem one involving only $A(t)$ and $\partial A(t) / \partial t$. 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).

Noting that

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

and

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

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

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

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

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

and

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

Using Equations A17–A21, the first of the two demand equations (Equation A22 corresponding to Equation 2 in the text) is derived. To obtain Equation A22, multiply equation A20 by $(1-\delta)$ and subtract the resulting equation from Equation A21. Replace $U_C(i)$ and $V_A(i)$ with their respective definitions given in Equations A17 and A18 and solve the remaining equation for $C(t)$.

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

where

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

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

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

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

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

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

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

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 3 in the text):

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

where

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

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

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

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

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

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

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