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The impact of addiction information on cigarette consumption

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The impact of addiction information on cigarette consumption

by

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For,

James, Stella and Ann

This paper is dedicated to my parents James and Stella who encouraged me to pursue my dreams even though they knew that I might choose to live in America. It is the fruits of their labor that enabled me to pursue my dreams.

My dissertation is also dedicated to my beloved wife Ann who is the best thing that ever happened to me. Her sacrifice and support are an inseparable part of this work and of both my graduate degrees.

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CHAPTER 1.
INTRODUCTION

The cigarette industry has been the subject of an enormous amount of research in economics. One need only look at the immense variation in cigarette consumption over time to understand the impetus for such endeavors. The industry has been the subject of government regulation and taxation for about the last thirty years. A look at the total annual and per capita cigarette consumption rates and the percentage change in per capita rates from year to year will serve as an illuminating backdrop for the research issues at hand. The data for cigarette consumption over the last ninety-five years are summarized graphically in Figures 1.1 through 1.3. The data are taken from the 1996, Tobacco Situation and Outlook Report.

An examination of Figures 1.1 through 1.3 reveals that perhaps the most obvious trend is the rapid increase in cigarette consumption since the 1900s. A perusal of the graphs shows that there have always been fluctuations in consumption levels from year to year. However, there has been a significant drop in per capita cigarette consumption since the mid-1960s and a drop in total cigarette consumption since the late 1970s. These negative trends have been attributed, in part, to a spate of health information about cigarettes that was publicized in the late sixties and the early seventies. The health warnings culminated with reports about the addictive nature of nicotine by the Surgeon General in 1979. This information is summarized in Table 1.1. Furthermore, according to the Surgeon General's Report (1986), cigarette smoking is the leading preventable cause of premature death and disability in the U.S.

Any economic analysis of cigarette smoking should possess an understanding of the reasons why consumers choose to smoke. The following is a brief summary of the motivation to smoke cigarettes. As Mullahy (1985) contends, consumers would not smoke

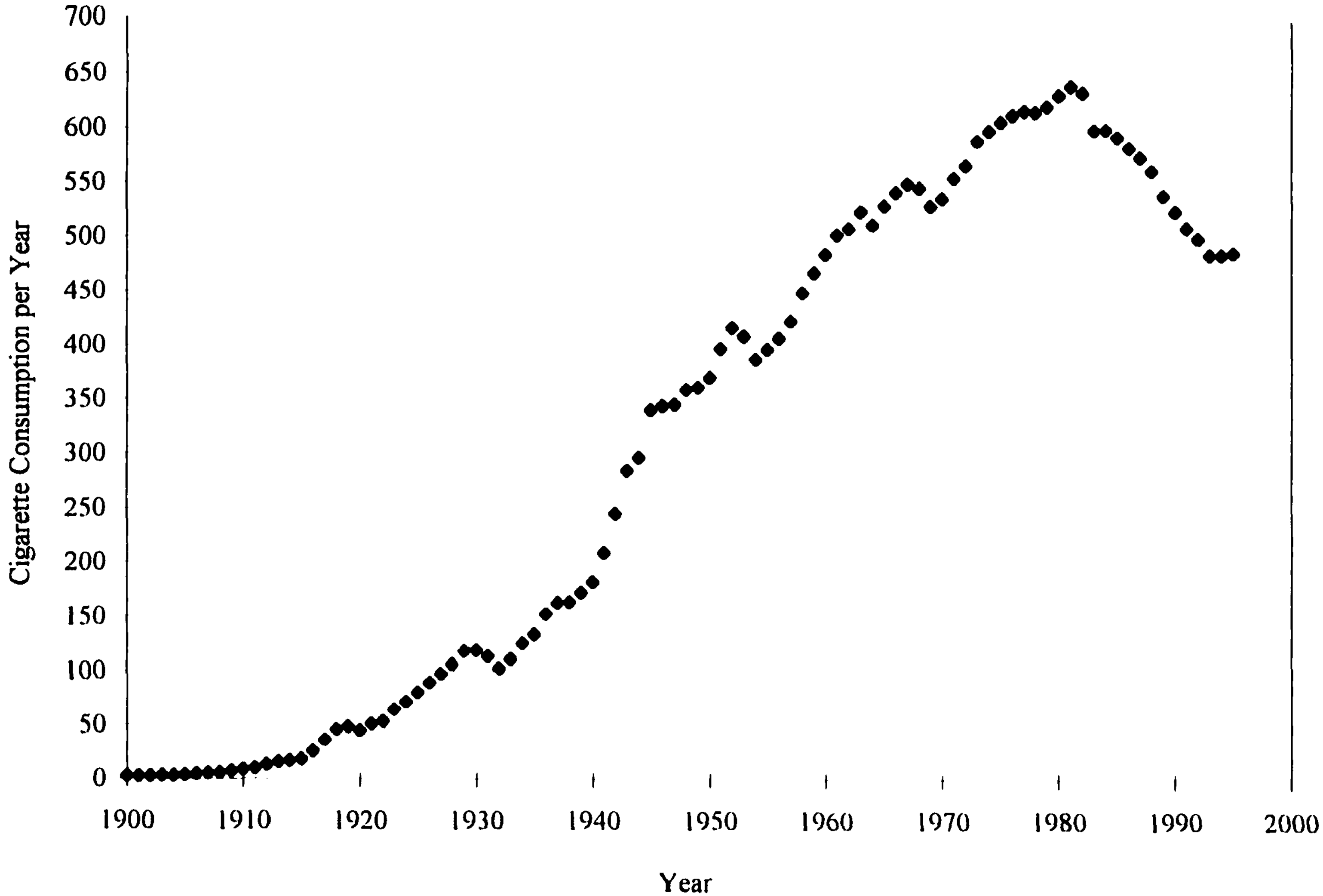

Figure 1.1 Annual Cigarette Consumption in Billions

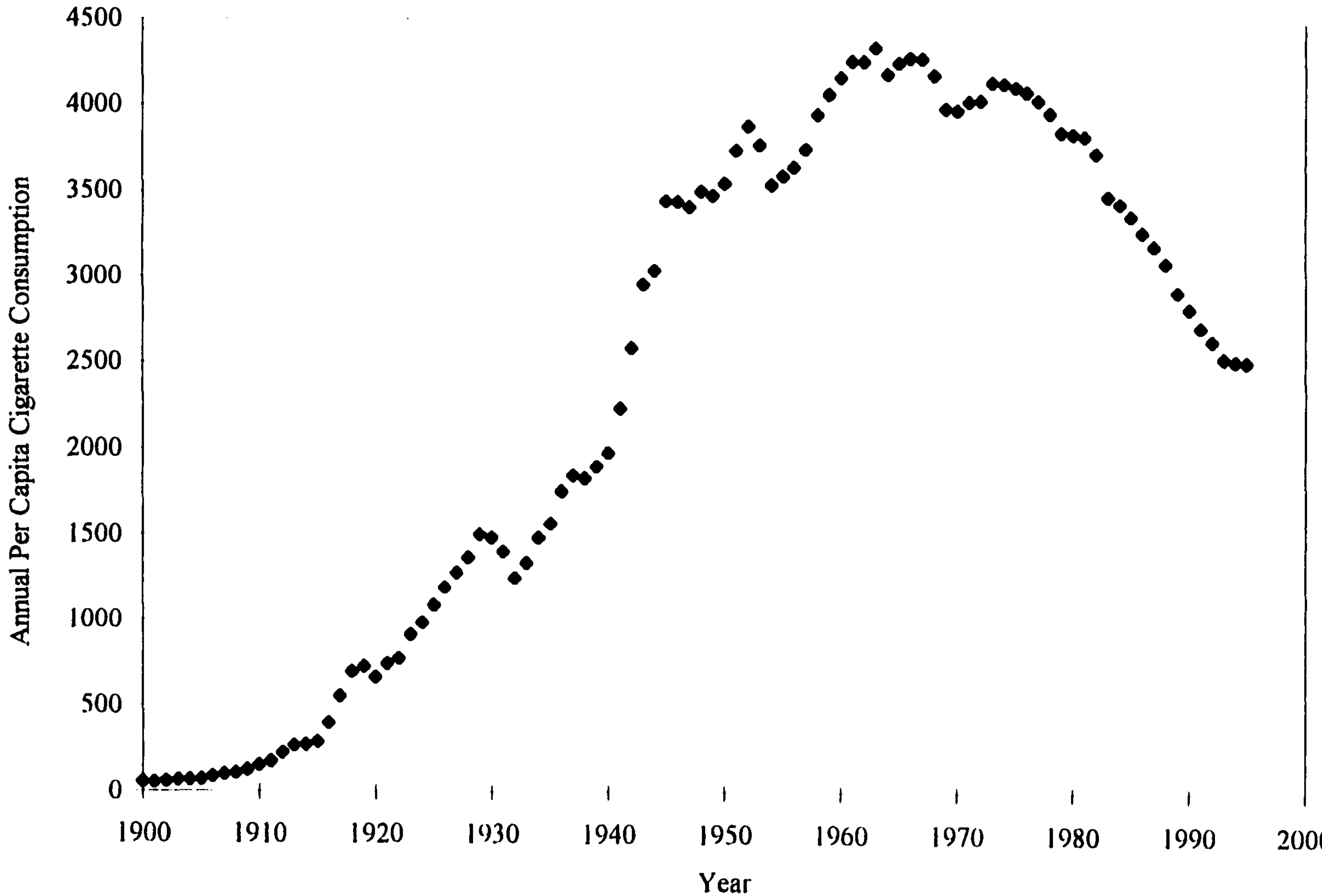

Figure 1.2 Per Capita Cigarette Consumption

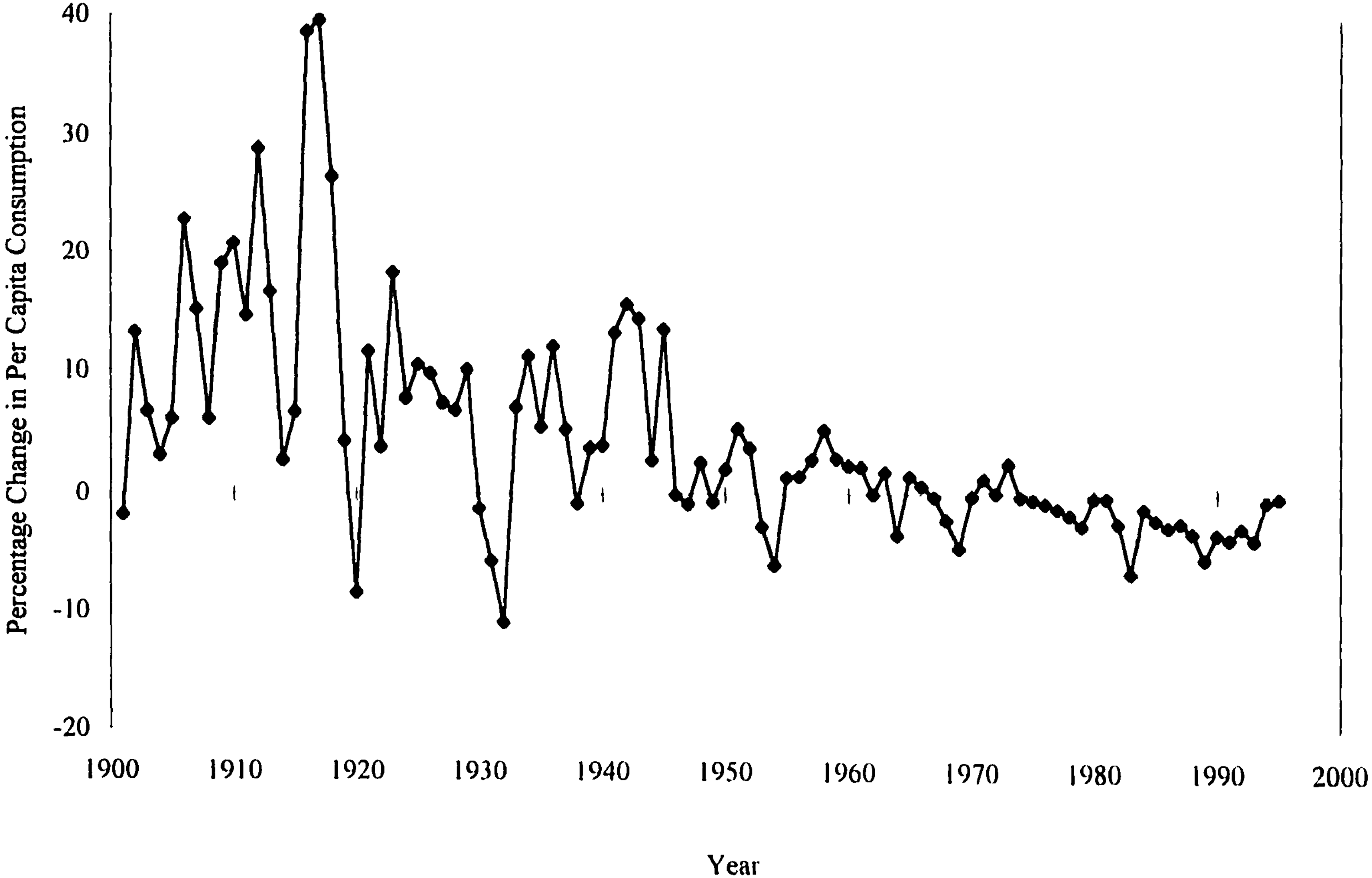

Figure 1.3 Percentage Change in Annual Per Capita Consumption

unless they experienced some benefits from consuming cigarettes. A better understanding of the process that generates these benefits is elucidated by Ashton and Stepney (1982). They maintain that cigarette smoking is desirable to some consumers because it produces pleasure or alleviates discomfort.

The specific mechanism by which cigarette smoke produces pleasure or alleviates discomfort can be broken down into nonpharmacological and pharmacological factors. Nonpharmacological factors refer to pleasure being generated from the smell and taste of smoking cigarettes. On the other hand, pharmacological factors describe the bio-chemical process through which cigarettes produce pleasure or alleviate discomfort. Ashton and Stepney maintain that smokers consume cigarettes primarily because of the pharmacological aspects of nicotine. They claim that cigarettes are smoked in order to deliver desirable amounts of nicotine to the user. In order to support this claim, they cite evidence of studies that report smokers who modify their behavior when smoking cigarettes that contain less nicotine. Smokers who consume low-nicotine cigarettes have been reported to take longer

Table 1.1 A Timeline of Health Warnings Regarding Cigarette Smoking

Year	Health Warnings
1953	American Cancer Society & British Medical Research Council's report on increased mortality rates due to smoking
1964	U.S. Surgeon General's Report linking smoking to cancer
1965	Cigarette Labeling & Advertising Act stipulates that health warnings are to be printed on packs
1968	F.C.C. Fairness Doctrine requires that one free anti-smoking commercial be aired for every four industry commercials
1971	Ban on all broadcast cigarette advertising
1979	Surgeon General's Report stating that cigarettes are addictive

and more frequent puffs and to inhale deeply in order to ingest the desired level of nicotine. They identify nicotine as the primary reinforcing agent in cigarette smoke.

The pharmacological process begins with the inhalation of cigarette smoke containing nicotine into the lungs. Upon absorption into the bloodstream, nicotine is rapidly delivered to most tissues that enjoy a copious blood supply. This includes the brain. Upon crossing the blood-brain barrier, nicotine emulates the natural neurotransmitter acetylcholine and bonds with the receptors in the nervous system. Nicotine is a biphasic drug because in small doses it acts as a stimulant whereas in larger doses it blocks the receptors and acts as a depressant. Thus, by varying the length and frequency of puffs, a smoker can use a cigarette to alleviate stress or to induce pleasure.

Cigarettes have been characterized as an addictive good. There are several definitions of addiction. In keeping with Chaloupka (1991), it is assumed that addiction refers to the simultaneous presence of reinforcement, tolerance and withdrawal. Ashton and Stepney describe reinforcement as a psychological mechanism whereby a behavior is influenced by its consequences. The size and frequency of the rewards associated with a given behavior influence the occurrence of that behavior. In other words, the more a person smokes, the more her body learns to relax or calm down in response to smoking. The U.S. Department of Health and Human Services (1982) states that tolerance refers to the practice of using increasing amounts of a substance to provide the original level of satisfaction. As cigarette smokers continue to smoke, they need larger doses of nicotine in order to achieve a given level of satisfaction. The increase in dosage is bounded because in large doses nicotine blocks the receptors. Furthermore, in its purest form a very small dose of nicotine can be lethal. Shiffman (1979) describes the symptoms of withdrawal as an intense craving for tobacco accompanied by weight gain, irritability and loss of sleep.

The addiction process begins with the experience of pleasurable sensations due to nicotine intake. It progresses further with the establishment of reinforcing effects.

Continued use of cigarettes causes the body to develop a tolerance to nicotine whereby larger doses are required to maintain satisfaction levels. Finally, the body gets accustomed to a fixed amount of nicotine and any attempt to reduce this amount results in the acute discomfort of withdrawal. It is at this stage that the smoker is hooked.

On July 19, 1995 the Journal of the American Medical Association published an article which alleged that the British American Tobacco Company and the Williamson Tobacco Corporation had learned about the addictive nature of nicotine in the early 1960s, Glantz et al. (1995). They go on to say that the U.S. Surgeon General did not learn about the addictive nature of nicotine until 1979. The following is a quote from this article:

> By the early 1960s the British American Tobacco Company (BAT) and Brown and Williamson Tobacco Corporation (B&W) had developed a sophisticated understanding of nicotine pharmacology and knew that nicotine was pharmacologically addictive. Publicly however, the tobacco industry has maintained and continues to maintain that nicotine is not addictive. The scientific community was much slower to appreciate nicotine addiction: the Surgeon General did not conclude that nicotine was addictive until 1979.

On April 1, 1994 the New York Times reported that Phillip Morris blocked a 1983 research report which concluded that nicotine was an addictive substance, Hilts (1994). Five years later, nicotine was again confirmed to be an addictive substance in a Surgeon General's report (1988) entitled The Health Consequences of Smoking: Nicotine Addiction. In recent times the cigarette industry has been in the press quite often. Several states in the U.S. are currently suing firms in the tobacco industry in order to recover health costs incurred by smokers. For example, the March 21, 1997 Des Moines Register reports that the state of Iowa is suing tobacco firms for violating the state's consumer fraud act by failing to disclose the dangers of smoking and the addictive qualities of nicotine, Vedantam (1997). The report goes on to say that the manufacturers of Chesterfield cigarettes, the Liggett Group, admitted in court that cigarettes are addictive and that the industry targets teenagers for sales. The

Liggett group has also turned over hundreds of documents on industry-wide discussions about the dangers of nicotine and marketing strategies. Given the efforts of the tobacco industry to conceal addiction information from the general public, a study of the impact of addiction information on cigarette demand is warranted. The results from such an investigation would not only be of interest to participants in the various lawsuits but also to policy makers whose goal is to reduce cigarette smoking.

The objective of this dissertation is to examine the impact of addiction information on the demand for cigarettes. This objective is accomplished and summarized by the procedures described in the chapters to follow. Chapter 2 begins with a systematic review of the theoretical models that explain the demand for addictive goods. The Becker and Murphy rational addiction model (1988) is identified as a relevant starting point for the theoretical model used in this study. Chapter 3 generalizes this model to generate the demand for both addictive and non-addictive goods and derives testable implications about the impact of addiction information on cigarette demand. Chapter 4 describes the collection of the data set, operationalizes the theoretical model developed in Chapter 2 and discusses the relevant econometric procedures that will be used to estimate the model. Chapter 5 presents the econometric results and discusses their economic implications. Finally, Chapter 6 summarizes the current research effort and suggests directions for future research.

CHAPTER 2.
LITERATURE REVIEW

An Overview of the Economic Aspects of Cigarettes

The purpose of this chapter is to review the literature relevant for the implications of the impact of addiction information on cigarette demand. There is a vast literature on the economic aspects of cigarettes. This literature can be loosely classified into three main branches. The demand side, the supply side and the literature on the health costs attributable to cigarette smoking. The current chapter will investigate the demand side of the literature at length.

The supply side literature focuses on issues of market structure and the behavior of a firm supplying an addictive good. In a very recent example, Barnett, Keeler and Hu (1995) develop a model of oligopoly price behavior and tax incidence for the U.S. cigarette industry. They find that competition among manufacturers has been decreasing since 1980. Also, Fethke and Jagannathan (1996) examine the behavior of consumption and price given that imperfectly competitive producers face consumers with different intensities of habit persistence.

The health cost literature focuses on the health costs of smoking to the smoker and to society at large. An example of this type of work is provided by Rice et al. (1986) who investigate the costs resulting from the health effects of smoking. They include expenditures for medical care and the value of lost output due to disability and premature mortality among cigarette smokers. The authors also do a comparative analysis of the utilization of medical care of smokers versus non-smokers.

The demand side is arguably the largest branch of the literature on cigarette smoking. Under this heading, one would group a plethora of issues such as: competing models of cigarette demand, the impact of excise taxes on cigarette smuggling, the importance of advertising on cigarette demand and the impact of health information on cigarette consumption. The next section will review studies that model the impact of the release of health information on cigarette demand. Ideally, a review of studies on the impact of information about addiction on cigarette demand would be desirable. However, since a literature search did not reveal any such studies, a review of the cigarette health information literature is relevant. After discussing the cigarette health information literature, this chapter turns to competing microeconomic models of cigarette demand. Finally, there is a detailed review of studies that discuss the development of the rational addiction model and its application to the cigarette industry.

Health Information Shocks and Cigarette Demand

Schneider, Klein and Murphy (1981) claim that the earliest example of public awareness about the health effects of cigarette smoking occurred in 1953 when the American Cancer Society and the British Medical Research Council published a report which stated that smokers had a higher death rate than non-smokers. Public interest in the health effects of smoking was further stimulated by the 1964 Surgeon General's Report which linked smoking to cancer. In 1965 the Cigarette Labeling and Advertising Act stipulated that health warnings were to be printed on cigarette packs. In 1968 the Federal Communication Commission's Fairness Doctrine required that one free anti-smoking commercial be aired for every four industry commercials on broadcast media. Finally, in 1971 all cigarette commercials were banned from the broadcast media. In 1979 another Surgeon General's report was published that supported the 1964 report and extended the link between cigarette smoking and various diseases. This report was also the first time that a Surgeon General's report discussed the addictive properties of nicotine. It is the impact of such events on cigarette consumption that are the subjects of the articles to which we now turn.

Economists in the 1970s were interested in investigating the impact of the above events on cigarette demand. The general methodology employed was to treat cigarettes as a non-addictive good and to model cigarette demand as a function of prices, income and a series of dummy variables that captured health scare or policy effects. Cigarette demand was not modeled as a function of either past or future prices. In other words, the early models treated consumers as naive agents that consumed cigarettes in a static framework without considering either the impact of the addictive nature of the good on future consumption or the dependence of current consumption patterns on past behavior. The initial work in the field tried to estimate the impact of taxes, advertising and health scares on the quantity demanded and on the elasticity of demand for cigarettes.

James Hamilton (1972) was one of the first to address the issue of the impact of health warnings on cigarette consumption and is extensively quoted in the literature. Hamilton states that when it comes to curtailing consumption, the health scare effect is relatively more powerful than the ban on cigarette advertising in the broadcast media. He uses data from 1925-1970 to model cigarette demand as a function of a wholesale price index, advertising expenditures and a series of dummy variables to capture health scare and policy effects. The dummy variables represent the 1953 American Cancer Society's Report, 1964 Surgeon General's Report and the 1968 anti-smoking campaign. Advertising was assumed to have a geometric lag structure. The demand function was estimated for both linear and log-linear specifications, using a couple of different advertising indices and for various time periods. Hamilton used his regression coefficients to make predictions at the mean. He found that the health scare was several times more powerful as a deterrent than advertising was as a stimulant. The linear estimates show that advertising boosts per capita consumption by 95 cigarettes per year, the 1964 Surgeon General's warning depressed per capita consumption by 252.9 cigarettes at the mean and antismoking commercials depressed per capita cigarette consumption by 530.7 units on average.

Several other studies followed Hamilton's research. Atkinson and Skegg (1973) examined the health scare question in the context of the U.K. They find that publicity concerning the harmful effects of tobacco has the effect of causing a sudden fall in consumption with a gradual return to the old level. Warner (1977) investigated the impact of the anti-smoking campaign on cigarette consumption. His results suggest that health warnings cause immediate but transitory decreases in cigarette consumption, whereas the cumulative effect of publicity is substantially greater in deterring consumption. Witt and Pass (1981) find for the U.S. and the U.K. that, while advertising tends to increase cigarette consumption, health scares decrease consumption by a small but significant amount of about 3-7% a year and in the subsequent year following the year of the health scare. They find that cigarette advertising expenditures in 1962 and 1963 would need to be doubled in order to effectively neutralize the effects of the 1962 health scare.

Baltagi and Levin (1986) have also been quoted extensively in this literature. Their panel data study examines the effects of bootlegging and cigarette taxation and finds mild support for the effectiveness of anti-smoking messages in reducing cigarette consumption. Bishop and Yoo (1985) use neoclassical microeconomic theory to identify the interactions between cigarette demand and supply. They then use a three stage least squares estimation procedure to evaluate the effects of cigarette taxes, advertising, the advertising ban and health scare on the industry's output. They find that demand is inelastic while supply is elastic. The authors also discovered that the impact of taxes was substantially larger than the impact of either the health scare or the television ban on cigarette advertising. Finally, they report that advertising increased cigarette demand only slightly.

The Federal Trade Commission was also actively involved in investigating the impact of cigarette health information on smoking. Ippolito, Murphy and Sant (1979) authored a

Federal Trade Commission report that was devoted to investigating consumer responses to cigarette health information. Their study provides an examination of the nature and extent of consumer reactions to the following health scares and policy changes: the health publicity of the 1950's; the 1964 Surgeon General's Report; the 1965 and 1970 cigarette package labeling regulations; the 1968-1971 anti-smoking commercials and the television and radio advertising ban of 1971. The authors find that Surgeon General's Report of 1964 affected per capita consumption very gradually. They found a drop in per capita cigarette consumption of about 3.5 percent a year from 1964-1975. They also found that the anti-smoking commercials were not very effective in intensifying the decline in per capita smoking rates. The authors also noted that the drop in smoking rates due to the publicity in the 1950's was primarily due to a reduction in the intensity of smokers' habits whereas the decline in smoking rates after the 1964 Surgeon General's Report was due to fewer adults smoking while the average number of cigarettes consumed by existing smokers remained unchanged.

Schneider, Klein and Murphy (1981) also investigated the impact of the 1953 and 1964 health scares on per capita cigarette consumption. However, they employ a notably different approach. They claim that the effectiveness of health warnings about the dangers of smoking can be observed by monitoring the rise in the consumption of low-tar and filter-tipped cigarettes. They also appear to be the first to model the impact of advertising via two stock variables, one for the pre-advertising ban period and one for the post-ban period. They use a double-log model to study per capita cigarette demand as a function of the retail price of cigarettes, per capita real income, two stocks of advertising, a dummy for the fairness doctrine period, the percentage of filter-tip cigarettes, the percentage of low-tar cigarettes, the average annual amount of tobacco per cigarette and an income instrument to model trend effects. The authors find that the total effect of the 1953 and 1964 health shocks is a forty-seven percent decline in per capita cigarette consumption by 1978.

Blaine and Reed (1994) provide a more recent attempt to model the impact of health information on cigarette demand. They model per capita cigarette consumption as a linear function of retail price, per capita income, the proportion of the adult population in the peak smoking group and the proportion of cigarettes sold with filter-tip and low tar and nicotine. They also include dummy variables that decay geometrically to model the impact of the 1954, 1964 and 1971 health scare events. Their results indicate that the invention of filter-tipped cigarettes have had a significant impact on consumption patterns. However, the low-tar and nicotine variables do not seem to mitigate the effects of the various health scares in their model.

All the studies reviewed seem to agree that the 1953 and 1964 health scares are significant in affecting cigarette consumption. However, the empirical evidence is mixed when it comes to the magnitude of the health scare effects as compared to the impact of the cigarette advertising ban of 1971. The literature also suggests that excise taxes are an important tool in curbing cigarette consumption. The only area of disagreement appears to be the impact of the anti-smoking commercials aired during 1968-1971 and, consequently, the relevance of the advertising ban of 1971. Authors such as Warner and Hamilton find anti-smoking commercials to be a potent weapon in countering cigarette advertising. Hence, they conclude that the ban on both positive and negative cigarette advertising serves to tip the scales in favor of the cigarette industry. Other authors such as Baltagi and Levin do not find such a powerful negative impact of the anti-smoking commercials. At best their results mildly support the efficacy of anti-smoking commercials in curtailing cigarette consumption. Thus, they find no evidence that a ban on both pro and anti-smoking commercials raises consumption. The next section will focus on the micro-foundations of modeling cigarette demand.

A Brief Introduction to Competing Models of Cigarette Demand

As is the case with many topics in economics, there are numerous studies on the demand for cigarettes and tobacco. The purpose of this section is to focus on that portion of the literature which addresses the theoretical microfoundations of modeling cigarette demand. In order to explore the plethora of studies that have been done on this aspect of cigarette consumption, it is useful to classify the literature. Figure 2.1 provides one such classification.

Non-addictive Specifications of Cigarette Demand

In the early 1970s some economists modeled the demand for cigarettes in the same way as the demand for non-addictive goods. For example, Hamilton (1972) and Warner (1977) estimate a demand function for cigarettes that depends primarily on income and cigarette prices. These early studies did not model cigarette demand as a function of either past or future consumption. Most of the studies on cigarette health information that were reviewed in the previous section would fall into this category.

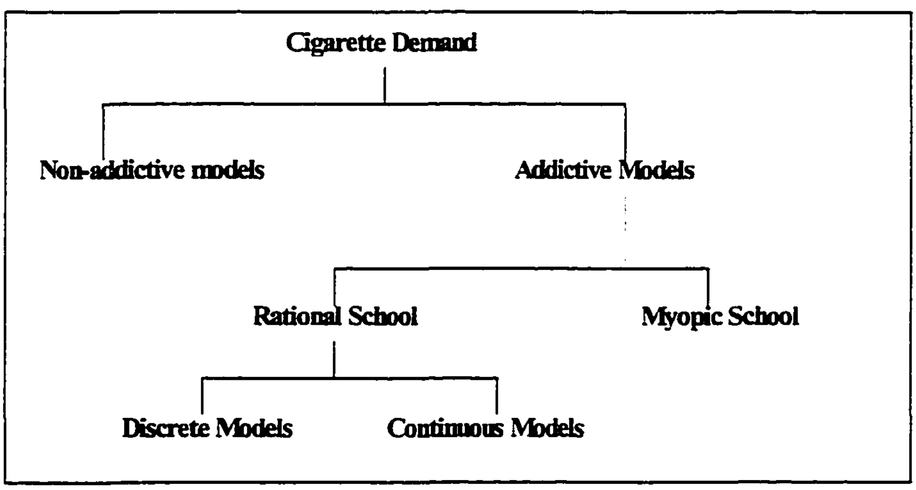

Figure 2.1: A Classification of Cigarette Demand Studies

Addictive Specifications of Cigarette Demand

Other economists did try to account for the habit forming nature of cigarettes and attempted to model their demand as a function of prices, income and past consumption. Houthaker and Taylor (1966) were perhaps the first to model the demand for cigarettes as a function of income, prices and a stock of past consumption. The distinguishing feature of the addictive models is that in addition to prices and income they model cigarette demand as a function of past consumption and/or prices and future consumption and/or prices.

Myopic Models of Addiction

Addictive models in turn can be divided into two categories: myopic models and rational models. Grossman (1991) points out that both myopic and rational models stress the dependence of present consumption on past consumption. However, myopic models fail to account for the effects of current consumption on future utility. In other words, myopic models produce demand functions for current consumption that are independent of future prices and future consumption levels. For example, Elster (1979), Schelling (1984), and Winston (1980) modeled the demand for addictive goods as dependent on past consumption. However, they did not consider the impact of current consumption on future choices.

Rational Models of Addiction

The rational school of addiction will be reviewed briefly here, because the next section is devoted to taking a detailed look at three versions of this model. The models of rational addiction can in turn be classified into their discrete and continuous counterparts. The terms discrete and continuous are used in keeping with the recreation demand literature, Freeman (1993). Discrete models refer to zero-one choice dependent variables whereas continuous models refer to dependent variables that can take on continuous values. Discrete models of rational addiction strive to explain starting and quitting rates among smokers. For example, Douglas and Hariharan (1994) estimate the probability of starting to smoke based on a forward looking utility maximization model that incorporates the stock of past consumption. Douglas (1998) provides the most recent example of this type of work. He uses a rational addiction based expected utility model to estimate the duration of the smoking habit along with the probabilities of starting and quitting.

On the other hand, continuous models of rational addiction seek to explain the relationship between the quantity of cigarettes smoked and the magnitude of past, present and future prices, income, advertising and the past stock of consumption. Although Becker and Murphy (1988) have become the main proponents of the continuous rational addiction model, earlier work by Spinnewyn (1981), Iannaccone (1984) and Stigler and Becker (1977) laid the foundation for a rational analysis of addictive behavior. Spinnewyn claimed that it is possible to model highly addictive goods based on a stable preference structure if one treats the amounts of addictive consumption (i.e.,, consumption as a result of craving in each time period) as a cost imposed on the agent given his original preferences. Under this approach, the agent maximizes intertemporal utility in each period subject to resource and minimum consumption constraints. One such constraint is to consume at least a given amount of the addictive good because of the impact of previous consumption.

Stigler and Becker incorporate Spinnewyn's ideas within a model of household production. The authors argue that agents do not consume goods but that they consume commodities that are produced by the agents themselves using market goods and human capital. Their justification for using a rational model to explain addictive behavior is as follows: Agents' preferences for an addictive commodity (not the same as an addictive good) are stable because the effects of the addictive nature of the good are accounted for in the device of consumption capital. Stigler and Becker give the example of music appreciation. They say that the bundle of commodities that a household consumes can be broken down into music appreciation and a vector of all other commodities. Music appreciation is in turn is produced by the time allocated to music and the human capital conducive to music appreciation. Subsequently, Stigler and Becker claim that human capital conducive to music appreciation is produced using inputs of educational attainment and previous amounts of music appreciation. It is through this household production approach that Stigler and Becker are able to account for the impact of past and future consumption of the addictive good on current consumption, without having to concede to a changing preference structure.

The attractive aspect of rational addiction theory is that it allows economists to bring most of their standard utility and demand theory tools to bear with a few adjustments. In addition, the rational model demonstrates theoretical superiority over the myopic school because myopic behavior is a subclass of the rational model and can be modeled as agents having an infinite rate of time preference for the present. As is the case with most theoretical debates, the proponents of the respective theories look to the data for support. Studies by Chaloupka (1991) and Becker et al. (1994) show that rational addiction models yield demand functions that do fit the data quite well; and of late, it is this school of thought that has dominated the economic research on modeling addiction.

Finally, it is appropriate to discuss the double hurdle model. The double hurdle model is an econometric technique that has been used to estimate the demand for cigarettes. Jones (1989) argues that in order to start smoking a potential smoker must clear two hurdles. First, the consumer must decide whether or not to smoke. Next, given that a consumer has decided to smoke, she must decide how much to smoke at the current prices and income level. Both these decisions can be modeled within either a myopic or a rational framework. Thus, the double hurdle model can be incorporated into either a myopic or a rational demand model. Having reviewed various competing microeconomic models of cigarette demand, it is appropriate to take a closer look at the leading model that is used to analyze the demand for cigarettes.

The Rational Addiction Model in Detail

The next three sub-sections will review three of the more prominent versions of the rational addiction model. The most extensively cited of these is the purely theoretical work of Becker and Murphy. This work was operationalized and tested empirically using panel data by Chaloupka. He found support for the main predictions of the Becker-Murphy model. Further support was provided for the theoretical work of Becker and Murphy by the time-series analysis of Becker et al. The Becker et al. time-series effort uses a discrete version of the rational addiction model developed by Becker and Murphy and can be shown to be a special case of Chaloupka's model. Since the theory that will be derived and implemented in this dissertation draws heavily upon the aforementioned works, it is important to review them in detail.

The Becker-Murphy Rational Addiction Model

Becker and Murphy state that even strong addictions are rational in that they are the result of forward-looking utility maximizing behavior with stable preferences. They claim to be the first to stress the importance of unstable steady-state consumption levels in explaining the addiction process. Their model shows that the long-run demand for addicts tends to be more elastic than the long-run demand for non-addicts. The Becker-Murphy model also explains phenomena such as binges and cold turkey within a utility maximizing framework. Finally, their model explains the relationship of temporarily stressful lifetime events to permanent addictions.

Becker and Murphy assume that utility at any point in time depends on C(t), the amount of the addictive good that is consumed; Y(t), the amount of the composite numeraire good; and S(t), the stock of consumption capital.

$$U(t) = u[Y(t), C(t), S(t)] \tag{2.1}$$

Past consumption of C affects this period's utility through S, which is said to accrue by a process of learning by doing. Consequently, current consumption of C has two effects. The immediate effect of C on current utility and the impact of C on future utility via the accrual of S. The utility function $u[\cdot]$ is assumed to be strictly concave in all its arguments. Given a constant rate of time preference σ and length of life T, the instantaneous utility function gives rise to the following lifetime utility function:

$$U(0) = \int_0^T e^{-\sigma t} u[C(t), Y(t), S(t)]dt. \tag{2.2}$$

The stock of consumption capital, S, or the addictive stock as it is also called accrues according to the following rule:

$$\dot{S}(t) = C(t) - \delta S(t) - h[D(t)]. \tag{2.3}$$

The time rate of change of the addictive stock, $\dot{S}(t)$, is given by the difference between the rate at which the stock accrues through current consumption and the rate of exogenous and endogenous depreciation of the addictive stock. δ reflects the rate of exogenous depreciation of the physical and mental effects of the drug. Becker and Murphy define D(t) as the expenditure by the agents to depreciate the addictive stock. However, in order to be consistent with their lifetime budget constraint, D(t) should be defined as the actual number of units of endogenous depreciation. The last piece of the puzzle is the lifetime budget constraint.

$$\int_0^T e^{-rt}[Y(t) + P_c(t)C(t) + P_d(t)D(t)]dt \leq A_0 + \int_0^T e^{-rt}w(S(t))dt \qquad (2.4)$$

The left hand side of equation (2.4) represents the present value of the continuously discounted sum of expenditures over the agent's lifetime. In each time period, these expenditures are comprised of the sum spent on the composite good, $Y(t)$ (which is also the numeraire with a price set to unity); the amount spent on the addictive good (which is the product of its price $P_c(t)$ and the quantity consumed $C(t)$); and the amount spent on endogenous depreciation of the addictive stock (which is the product of its price $P_d(t)$ multiplied by the quantity $D(t)$). The right hand side of the lifetime budget constraint represents the present value of the continuously discounted sum of earnings by the agent. A_0 is the initial value of assets. The agent's earnings function at time t, $w(S(t))$, is assumed to be a concave function of the addictive stock. The market rate of interest is assumed to be r. Finally, in order to state a lifetime budget constraint, Becker and Murphy assume that capital markets are perfect, thus allowing an agent to borrow against future earnings.

The rational addict maximizes her lifetime utility function given by equation (2.2) subject to the addictive stock constraint and the lifetime budget constraint given by equations (2.3) and (2.4), respectively. The Becker-Murphy first order conditions of the above problem provide useful insights into various facets of addictive behavior. However, it should be noted that in order to obtain the precise form of their first order conditions, the additional assumption of $\sigma = r$ is required. They do not make this assumption explicit until a later section in their paper. The first order conditions derived from equations (2.1) through (2.4) are the following:

$$u_y(t) = \mu e^{(\sigma - r)t} \tag{2.5}$$

$$h_d(t)a(t) = \mu P_d(t)e^{(\sigma - r)t} \tag{2.6}$$

$$u_c(t) = \mu P_c(t)e^{(\sigma - r)t} - a(t) \equiv \Pi_c(t) \tag{2.7}$$

where a(t) is defined as follows:

$$a(t) \equiv \int_t^T e^{-(\sigma + \delta)(\tau - t)} u_s d\tau + \int_t^T e^{-(r + \delta)(\tau - t)} w_s d\tau. \tag{2.8}$$

Note that μ represents the Lagrange multiplier which can be interpreted as the marginal utility of wealth in this problem. Equation (2.6) states that the marginal utility of consumption from the composite good at any point in time, y(t), equals the marginal utility of wealth. If $\sigma = r$, as is presupposed for the derivation of equations (2.6) and (2.7), then the exponential term in equation (2.5) reduces to unity. Equations (2.6) and (2.7) both contain the term a(t) which is defined by equation (2.8). The term a(t) is used to symbolize what Becker and Murphy refer to as the shadow price of an additional unit of the addictive stock. It represents the costs of discounted future utility and wages as the result of increasing the addictive stock S by a single unit at the margin. The impact of an additional unit of stock on utility and wages is negative by assumption, i.e., $u_s < 0$ and $W_s < 0$.

Becker and Murphy say that equation (2.6) implies that the expenditure on endogenous depreciation D will rise as the shadow price a(t) declines. Finally equation (2.7) brings us to the tradeoffs faced by a rational addict in determining the optimal amount of consumption of the addictive good. The term $\Pi_c(t)$ in equation (2.7) is called the full price of the addictive good. This is because it consists of the time discounted money price of the good and the time discounted price the agent pays in terms of lowered future utility and wages as a result of consuming the good. The marginal impact of S on utility and wages is negative by assumption. Thus, an agent determines the optimal level of C by equating the marginal utility of C to Π_C (t), the full price of consumption. In other words, a rational agent determines the optimal amount of consumption of the addictive good by weighing the current marginal utility of the good against the money price of the good and the costs imposed upon future utility and wages.

For the next part of their article, Becker and Murphy further assume that D(t) = 0 and σ = r. Equations (2.5), (2.6) and (2.7) can be manipulated to yield a second order linear differential equation in S(t), which is the Euler equation for the system. The solution of this Euler equation yields the following optimal time path for S(t)

$$S(t) = (S_0 - S^*)e^{\lambda_1 t} + S^* \tag{2.9}$$

where S_0 is the initial value of the addictive stock, S^* is the steady-state value of the addictive stock and λ_1 is the smaller root of the Euler equation for S(t). Plugging the solution for S(t) from equation (2.9) into the addictive stock constraint given by equation (2.3) with D(t) = 0 yields the following optimal time path for C(t), the consumption of the addictive good

$$C(t) = (\delta + \lambda_1)S(t) - \lambda_1 S^* . \tag{2.10}$$

Becker and Murphy, then use equations (2.9) and (2.10) to illustrate how their model explains the process of getting hooked and other addiction phenomena such as binges and cold turkey. Their definition of addiction is merely a situation where the current consumption of the addictive good leads to an increase in the future consumption of that good. Analytically speaking, this corresponds to an increase in consumption due to an increase in the addictive stock of the good. Thus, equation (2.10) provides the following condition for addiction:

$$\frac{\partial C(t)}{\partial S(t)} \geq 0 \quad \text{as} \quad (\delta + \lambda_1) \geq 0. \tag{2.11}$$

Their analysis of the time path of S(t) indicates that if an agent accrues more than a critical level of the addictive stock, then that agent gets hooked to the addictive good. If the agent is at a level below the critical stock, then ceteris paribus over time the agent will reduce consumption of the addictive good until abstinence is the final outcome. Thus, agents that experience a temporarily stressful event that raises their additive stock above the critical level will develop a permanent addiction. Their analysis of the time path of S(t) also shows that for sufficiently strong addictions the time path of S(t) becomes discontinuous at some level of stock, S_{min} going to zero below S_{min}. Thus, for agents that are strongly addicted, the rational addiction model predicts that if their level of addictive stock falls below S_{min}, they will find it optimal to go cold turkey in order to quit their habit.

The common belief about addictive goods is that their demand is insensitive to price because of the habit forming nature of the good. However, the Becker-Murphy first order conditions show an explicit role for price in the amount of the addictive good consumed. In fact their model suggests that since current consumption may impact future consumption through the addictive stock, a drop in current price may have larger effects for the long-run demand of an addictive good than a non-addictive good, because the price cut not only increases current consumption but also impacts upon future consumption through the addictive stock. Thus, the work of Becker and Murphy provides testable implications regarding the behavior of addicts. Chaloupka (1991) was among the first to operationalize their theory and derive tractable demand equations for the addictive good. Becker et al. (1994) also develop an empirical model to test the Becker-Murphy theory of rational addiction. This latter model turns out to be a sub-class of Chaloupka's model. A detailed review of the models which yield these tractable demand functions for addictive goods follows.

Chaloupka's Model of Rational Addiction

This sub-section will attempt to provide a detailed look at a simplified version of the Becker-Murphy model as proposed by Frank Chaloupka. The purpose of this sub-section is to fully understand the derivation of the dynamic demand equations using a quadratic utility function. This approach accounts for the addictive nature of the good by appealing to Becker's household production theory, as well as by incorporating features of addictive goods such as tolerance, reinforcement and withdrawal in the specification of the utility function.

In the tradition of Becker and Murphy, Chaloupka models utility as a function of health H(t), relaxation due to addictive consumption R(t) and a composite of other commodities Z(t).

$$U(t) = u[H(t), R(t), Z(t)] \tag{2.12}$$

Health H(t), in turn, is produced by a vector of market goods M(t) and the addictive stock of the good A(t).

$$H(t) = H[M(t), A(t)] \tag{2.13}$$

Increases in the addictive stock impact health adversely at an increasing rate ($H_A < 0$ and $H_{AA} < 0$). On the other hand, an increase in the quantity of market inputs is beneficial for health but at a decreasing rate ($H_M > 0$ and $H_{MM} < 0$). These relationships are graphed in Figures 2.2 and 2.3. Relaxation R(t) is produced as a function of the amount of cigarettes consumed at a point in time C(t) and the addictive stock A(t).

$$R(t) = R[C(t), A(t)] \tag{2.14}$$

Increases in cigarette consumption increase relaxation but at a diminishing rate ($R_C > 0$, $R_{CC} < 0$). In order to incorporate the concept of tolerance, it is assumed that increases in the addictive stock decrease relaxation at an increasing rate ($R_A < 0$, $R_{AA} < 0$). These relationships are graphed in Figures 2.4 and 2.5. Finally, in order to incorporate reinforcement, it is assumed that for any given level of consumption an increase in the addictive stock will lead to a higher level of relaxation ($R_{CA} > 0$). Figure 2.6 shows that at greater levels of A, R_C is larger. This is what is conveyed by $R_{CA} > 0$. Thus CD is steeper than AB. However, since $R_A < 0$, CD must lie below AB. The composite good Z(t) is produced using X(t), a vector of market goods, and the individual's own time.

$$Z(t) = Z[X(t)] \tag{2.15}$$

Here again we make the standard assumption of positive but diminishing marginal productivity ($Z_X > 0$, $Z_{XX} < 0$).

Given the above household production mechanism, Chaloupka obtains the derived instantaneous utility function by substituting for H(t), R(t) and Z(t) from equations (2.13)-(2.15) into equation (2.12), yielding

$$U(t) = u[R[C(t), A(t)], H[M(t), A(t)], Z[X(t)]] \tag{2.16}$$

or, in reduced form,

$$U(t) = U[C(t), A(t), Y(t)] \tag{2.17}$$

where Y(t) is a vector of goods used in the production of health and the composite good Z(t), (i.e., $Y(t) \equiv [M(t), X(t)]$). Since the substitution of R[ ], H[ ] and Z[ ] into (2.16) may result

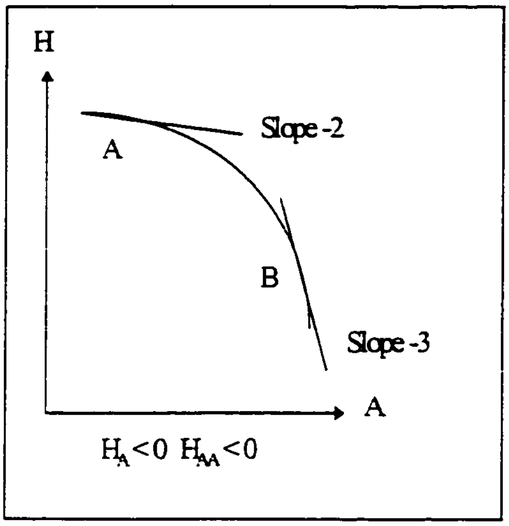

Figure 2.2: Health and Addictive Stock

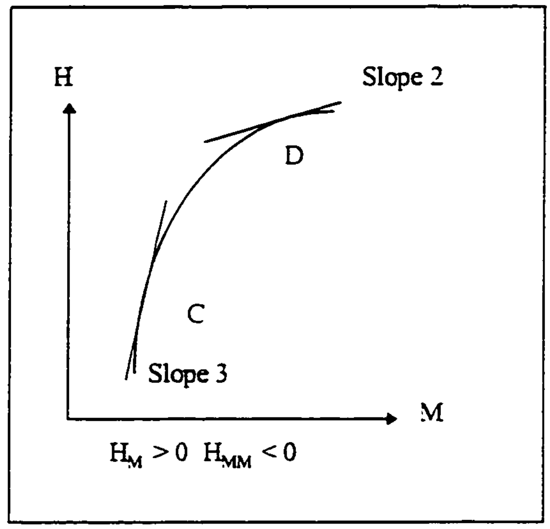

Figure 2.3: Health and Market Goods

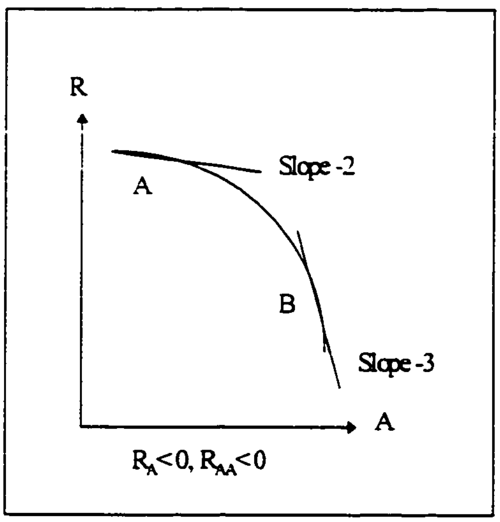

Figure 2.4: Relaxation and Addictive Stock

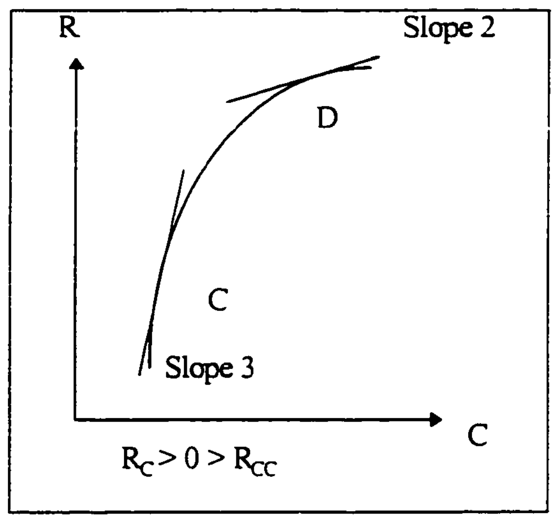

Figure 2.5: Relaxation and Smoking

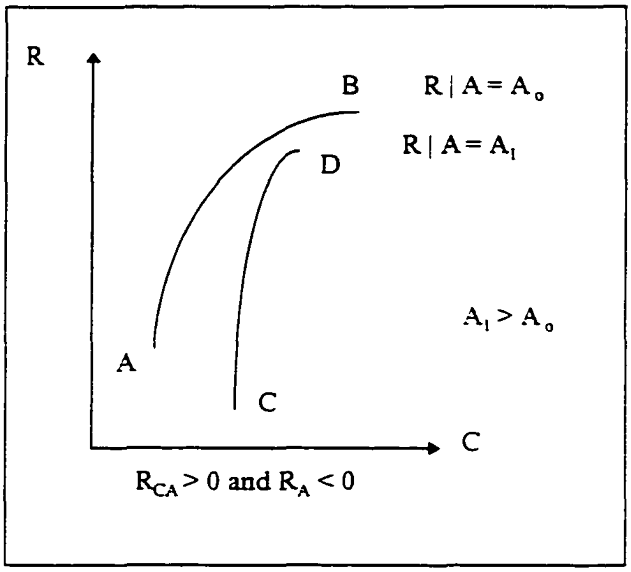

Figure 2.6: Reinforcement, Consumption and the Addictive Stock

in a change in the exact form taken by the function u, it is appropriate to designate the new reduced form function as U[ ].

Chaloupka uses equation (2.16) to demonstrate how the model incorporates concepts such as tolerance, reinforcement and withdrawal. Tolerance refers to the phenomenon of achieving a lower level of response from a given amount of the addictive substance. Thus, as the level of cumulative past consumption rises, an agent would receive a lower level of satisfaction from each additional unit of the substance. The model incorporates this feature as is evidenced by the sign of the partial derivative of equation (2.16) with respect to A.

$$U_A = \underset{(+)}{u_R}\,\underset{(-)}{R_A} + \underset{(+)}{u_H}\,\underset{(-)}{H_A} < 0 \qquad (2.18)$$

Withdrawal, on the other hand, refers to adverse physical effects that result from a reduction in consumption of the addictive substance. In other words, withdrawal is evidenced by a reduction in utility due to a reduction or termination of consumption. This is demonstrated by

$$U_C = \underset{(+)}{u_R}\,\underset{(+)}{R_C} > 0. \tag{2.19}$$

Finally, reinforcement refers to the increasing benefits from each additional unit of the substance as the agent's past experience with the drug increases. One might think of reinforcement as the body's ability to relax more with the incremental unit of consumption as a result of a learned response based on past consumption. Reinforcement says that for any given level of consumption, the larger the addictive stock, the larger the increase in relaxation and, hence, in utility.

$$U_{CA} = (\underset{(-)}{u_{RR}}\,\underset{(-)}{R_A})\underset{(+)}{R_C} + (\underset{(+)}{R_{CA}}\,\underset{(+)}{u_R}) > 0 \tag{2.20}$$

Equation (2.17) gives rise to the following lifetime utility function

$$U = \int_0^\infty e^{-\sigma t}\,U[C(t), A(t), Y(t)]dt. \tag{2.21}$$

The lifetime utility function is just a continuous sum of the discounted instantaneous utility functions (2.17) at each point in time where σ represents the agent's personal rate of time preference.

Just as in any other consumer problem, the agent is subject to a budget constraint. In his model, Chaloupka assumes that capital markets are perfect, so that the total amount of income available to the agent at any point in time is R(0), the present discounted value of lifetime earnings and assets. Chaloupka also assumes that Y(t) is the numeraire good (That is, the price of Y(t), $P_y(t)$, is unity with all other prices being measured relative to $P_y(t)$). Chaloupka obtains the following lifetime budget constraint

$$\int_0^\infty e^{-rt}[Y(t)+P_c(t)C(t)]dt \leq R(0) \tag{2.22}$$

where r represents the market rate of interest. $P_c(t)$ is the monetary price of cigarettes at time t. The lifetime budget constraint says that at any point in time expenditures on goods must be such that the sum of those expenditures over the agent's lifetime cannot exceed the present value of lifetime earnings and assets.

The agent's maximization problem is subject to another constraint which Chaloupka calls the "Investment Function." This constraint must be satisfied at each point in time. It is a differential equation which gives the relationship between the consumption of cigarettes and the addictive stock of the good.

$$\dot{A}(t) \equiv \frac{\partial A(t)}{\partial t} = C(t) - \delta A(t) \tag{2.23}$$

$$A(0) = A_0 \tag{2.24}$$

where A(t) is the addictive stock of cigarettes at time t, C(t) is the consumption of cigarettes at time t, δ is the depreciation rate of the addictive stock, A(0) is the initial addictive stock and $\dot{A}(t)$ is the time rate of change of the addictive stock.

C(t) influences future consumption levels through its impact on the time rate of change of the addictive stock of cigarettes. The constraint implies that the rate of change of the addictive stock of cigarettes at an instant in time is equal to the current amount of cigarette consumption less a depreciation factor $\delta A(t)$. A more intuitive understanding of the addictive stock concept is possible by examining the general solution to equation (2.23).

This differential equation has a time dependent coefficient and time dependent term. It may be solved using the integrating factor approach. The solution is as follows:

$$A(t) = e^{-\delta t}[A(0) + \int_0^t C(v)e^{\delta v}dv]. \tag{2.25}$$

The details of the solution are contained in Appendix A. Equation (2.25) implies that at any point in time t, the addictive stock A(t) of an agent is equal to the depreciation discounted value of the initial addictive stock A(0) and a cumulative sum from time zero until the present of depreciation discounted cigarette consumption at each point in time. If the initial addictive stock is zero, then the current addictive stock reduces to a discounted sum of past cigarette consumption.

At this point it may be useful to elucidate how Chaloupka's rational addiction model explains the consumption of an addictive good within the context of a stable preference structure. In keeping with Becker and Murphy, Chaloupka's model postulates that the addictive good is used in combination with other goods and the agent's time to produce a commodity, relaxation, which the agent then proceeds to consume. The key issue here is that the agent's preferences for relaxation in relation to other commodities remain unchanged over a period of time. It is possible for the agent to become highly addicted to the good being used to produce relaxation (e.g. cigarettes). However, within the context of the household production framework, an increase in the addictive stock just means that the agent needs to consume more cigarettes in order to achieve a given level of relaxation. It does not mean that the agent's preferences for relaxation have changed. It is this reasoning which allows the rational addiction models to maintain a stable preference structure.

The agent's lifetime utility maximization problem may be stated as follows:

$$\underset{C(t),Y(t)}{\mathrm{Max}} \int_0^{\infty} e^{-\sigma t} U[C(t), A(t), Y(t)]dt$$

subject to

$$\int_0^{\infty} e^{-rt}[Y(t) + P_c(t)C(t)]dt \leq R(0)$$

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

$$A(0) = A_0. \tag{2.26}$$

The first order conditions are:

$$U_Y(t) = \mu e^{(\sigma - r)t} \tag{2.27}$$

$$U_C(t) = \mu e^{(\sigma - r)t} P_c(t) - e^{\sigma t}\lambda(t) \tag{2.28}$$

According to equation (2.27), the marginal utility of the numeraire at any point in time t is equal to the shadow value of the lifetime budget constraint μ discounted continuously at the rate given by the difference between the personal rate of time preference and the market rate of interest. Equation (2.28) suggests that a first order condition for utility maximization is that the agent equates the marginal utility of consumption of cigarettes at time t to the difference between the marginal utility of the numeraire Y multiplied by the current price of cigarettes $P_C(t)$ and the continuously discounted shadow value of the addictive stock $\lambda(t)$. The shadow value of the addictive stock $\lambda(t)$ is the change in total utility that results from changing the level of the addictive stock by a single unit. However, since there is no market for addictive stock, the agent must discount the impact of the additional stock at the personal rate of time preference σ.

Chaloupka's model differs from the Becker-Murphy framework in several respects. Chaloupka does not explicitly consider the impact of the addictive stock on the agent's wage rate. He just assumes that the present value of the agent's lifetime earnings and assets is given by R(0). Unlike Becker and Murphy, Chaloupka does not explicitly consider the role of endogenous depreciation of consumption capital. He assumes no endogenous depreciation of the addictive stock in his model. Finally, Chaloupka's work differs from the Becker-Murphy model in that it is an applied piece. He derives specific demand functions for the addictive goods given by equations (2.30) and (2.31), unlike Becker and Murphy who only characterize addictive behavior by the time paths of consumption and the addictive stock given by equations (2.9) and (2.10).

Deriving Specific Demand Functions

Having set up the general framework for an addictive consumer, Chaloupka proceeds by assuming that the instantaneous utility function as represented by equation (2.17) takes the form of a quadratic function in C(t), Y(t) and A(t). In order to simplify the analysis, the additional assumption is made that the consumer's rate of time preference equals the market rate of interest (i.e., $\sigma = r$). He has the following instantaneous quadratic utility function

$$U(t) = b_Y Y(t) + b_C(t)\, C(t) + b_A A(t) + 1/2\, U_{YY} Y(t)^2 + 1/2\, U_{CC} C(t)^2$$
$$+ 1/2\, U_{AA} A(t)^2 + U_{YA} Y(t)A(t) + U_{CA} C(t)A(t) + U_{YC} Y(t)C(t). \qquad (2.29)$$

Maximizing equation (2.29) with respect to Y(t), converting to discrete time in the interest of obtaining analytically tractable demand functions and using the first order conditions that result from problem (2.26), Chaloupka obtains the following demand equations:

$$C(t) = \beta_0 + \beta_1 P_c(t) + \beta_2 P_c(t-1) + \beta_3 P_c(t+1) + \beta_4 C(t-1) + \beta_5 C(t+1) \qquad (2.30)$$

$$C(t) = \phi_0 + \phi_1 P_c(t) + \phi_2 P_c(t+1) + \phi_3 C(t+1) + \phi_4 A(t). \qquad (2.31)$$

Equations (2.30) and (2.31) are the dynamic demand equations for the addictive good based on a model of rational addiction. Equation (2.30) states that the current level of cigarette demand in period t depends upon the prices of cigarettes in periods t, (t-1) and (t+1). It also depends upon consumption in period (t-1) and on the next period's consumption. Equation (2.31) models current cigarette demand as being dependent on this period's price, next period's price and consumption and the level of this period's addictive stock. The appearance of some of these explanatory variables deserves further explanation. The above demand equations have been derived based on the underlying theory of rational addiction. Simply stated, the theory says that consumers are aware of the future costs of current actions and take these into account while making current consumption decisions. For example, the longer a person smokes, the more intense and prolonged the withdrawal symptoms. This is modeled by including the current addictive stock in equation (2.31). Another future cost that the rational consumer considers is the future price of cigarettes. Thus, P(t+1) is present in equation (2.30). Since addiction by its very nature causes the level of current consumption to be influenced by past consumption and since past consumption in turn is influenced by past prices, P(t-1) is included in equation (2.30). Chaloupka, Becker and Murphy characterize rational models as models in which agents are aware of and account for the interdependence of past, current and future consumption decisions. Furthermore, in a rational addiction model agents are assumed to keep these interdependent relationships in mind while making current consumption decisions. Hence, current, past and future prices and the addictive stock appear in the above demand equations.

Myopic demand equations are a subclass of the above demand equations. They can be obtained by assuming an infinite rate of time preference because myopic agents place all the weight on the current period's utility and discount the utility of all future periods at an infinite rate such that their present value is zero. As is to be expected of short-sighted agents, future prices do not enter into their demand equations. This is an important distinction between the two models, because it directly impacts upon the form of demand equation to be estimated. If the world were indeed myopic, then estimating rational demand equations would merely yield estimates of the coefficients of future price that are not significantly different from zero. Thus, not much is lost by using the rational model as a basic paradigm of addictive behavior because it does indeed encompass the realm of myopic behavior.

Chaloupka uses equations (2.30) and (2.31) to derive long-run elasticities for the respective demand functions when consumption is at its steady state value C^*. The steady state version of equations (2.30) is:

$$C^* = \beta_o + \beta_1 P_c(t) + \beta_2 P_c(t-1) + \beta_3 P_c(t+1) + \beta_4 C^* + \beta_5 C^* \tag{2.32}$$

Upon simplification we get:

$$C^* = \frac{\beta_o + \beta_1 P_c(t) + \beta_2 P_c(t-1) + \beta_3 P_c(t+1)}{1 - \beta_4 - \beta_5}. \tag{2.33}$$

Thus, the long-run own price elasticity for equation (2.33) is given by:

$$\frac{\partial C^*}{\partial P}\frac{P}{C} = \frac{[(\beta_1 + \beta_2 + \beta_3)/(1 - \beta_4 - \beta_5)]P}{C^*}. \tag{2.34}$$

The steady state version of equation (2.31) is:

$$C^* = \phi_o + \phi_1 P_c(t) + \phi_2 P_c(t+1) + \phi_3 C^* + \phi_4 \frac{C^*}{\delta}. \tag{2.35}$$

Upon simplification this yields:

$$C^* = \frac{[\phi_o + \phi_1 P_c(t) + \phi_2 P_c(t+1)]}{[1 - \phi - \frac{\phi_4}{\delta}]}. \tag{2.36}$$

Thus, the long-run own price elasticity for equation (2.36) is given by:

$$\frac{\partial C^*}{\partial P}\frac{P}{C} = \frac{[(\phi_1 + \phi_2)/\{1-\phi_3-(\phi_4/\delta)\}]P}{C^*}. \tag{2.37}$$

Empirical Framework and Results

It is useful to review the empirical results of Chaloupka's study which support the Becker-Murphy model. Cigarette consumption data from 1976-1980, obtained from the Second National Health and Nutrition Examination Survey on 28,000 people aged six months to 74 years were used. In order to estimate equation (2.30), three consecutive periods of consumption data are required. However, only two were available for Chaloupka. Therefore, Chaloupka addresses this problem by treating past consumption as current consumption and by treating current consumption as future consumption. He then simulates past consumption as being either zero for non-smokers or equal to the maximum consumption for smokers and former smokers.

Chaloupka estimates the addictive stock for non-smokers by the following expression:

$$A(t) = \sum_{t=0}^{t-1}(1-\delta)^{t-1-i}C(i). \tag{2.38}$$

In order to estimate equations (2.30) and (2.31), Chaloupka collected data on current consumption, current price, future price and lagged consumption by county of residence. Due to the endogeneity of current consumption with past and future consumption in equation (2.30) or with the addictive stock and future consumption in equation (2.31), Chaloupka uses an instrumental variable technique for estimating these equations. The instruments used to measure lagged and lead consumption were all past, current and future real cigarette prices.

Similarly, the instrumental variables used to measure the addictive stock and future consumption were current, lagged and lead real cigarette prices and current, lagged and lead excise taxes. Other variables that were included in the regressions were age, age squared, sex, race, family income, educational attainment, a set of excise taxes and marital and labor force status. Chaloupka was aware of the county of residence of each consumer. In an attempt to control for border crossover bias, Chaloupka uses an equally weighted average of the border price and the local price of cigarettes. Border crossover refers to the practice of individuals from a high tax area crossing the county or state border to purchase cigarettes in a lower tax area. The border price is defined as the lowest price within twenty five miles of the county of residence.

The estimated long-run price elasticity of demand for the full sample varies between -0.36 and -0.27. Chaloupka maintains that these are substantially higher estimates than those obtained from non-addictive cigarette consumption models. As per the predictions of the rational model, the estimates show that past and future consumption do indeed have significant and positive effects on current consumption. Furthermore, past and future prices have a positive effect on current consumption.

In order to examine the impact of time preference on demand, Chaloupka estimates demand equations separately for groups differing in age and educational attainment. The results show that less educated agents tend to behave more myopically than others. Present oriented individuals are expected to be more responsive to the market price of the addictive good than future oriented agents because, for myopic agents, the impact of current consumption on future utility is heavily discounted. The results of Chaloupka's study support the predictions of the Becker-Murphy model of rational addiction.

Becker-Grossman-Murphy Tests of the Rational Addiction Model

Becker et al. provide further empirical support for the Becker-Murphy theory of rational addiction. They are the first to derive rational addiction demand equations for cigarettes using a completely discrete approach. Both Becker and Murphy and Chaloupka have appealed to continuous models at some point or other. Becker et al. use annual data that is disaggregated by state for the U.S. for the period 1955-1985. They operationalize the theory of Becker and Murphy by developing an empirically testable demand equation. Next, they use this equation to identify and test some of the theoretical implications of the Becker-Murphy model.

Becker et al. propose the following discrete instantaneous utility function:

$$U_t = U(Y_t, C_t, C_{t-1}, e_t) \tag{2.39}$$

where U_t is the utility at time t, Y_t is the amount of the composite or numeraire good at time t, C_t is the amount of the addictive good consumed at time t, C_{t-1} is the previous period's consumption of the addictive good and e_t measures other period t unobservable life-cycle variables that impact utility. Note that the addictive stock A_t is represented by C_{t-1}. This will be discussed in greater detail when the addictive stock constraint is reviewed. Becker et al. assume that individuals live forever and that they maximize the sum of their lifetime utility discounted at the market rate of interest r. This gives rise to the following lifetime utility function:

$$U(0) = \sum_{t=1}^{\infty} \beta^{t-1} U(Y_t, C_t, C_{t-1}, e_t) \tag{2.40}$$

where $\beta \equiv \dfrac{1}{(1+r)}$.

The lifetime budget constraint is given by:

$$\sum_{t=1}^{\infty} \beta^{t-1}(Y_t + P_t C_t) = A_0 \tag{2.41}$$

where A_0 is the present value of lifetime wealth. Finally, the discrete version of the addictive stock constraint is given by:

$$A_t = C_{t-1} + (1-\delta)A_{t-1}. \tag{2.42}$$

Equation (2.42) suggests that this period's addictive stock A_t is equal to last period's consumption plus the undepreciated portion (1-δ) of last period's addictive stock. Becker et al. assume a depreciation rate of one-hundred percent, i.e., $\delta = 1$. Thus, $A_t = C_{t-1}$. Hence, A_t does not appear in the utility function given by equation (2.40).

The consumer maximizes lifetime utility given by equation (2.40) subject to an initial value of consumption C^0 and the lifetime budget and addictive stock constraints given by equations (2.41) and (2.42) respectively. The resulting first order conditions are:

$$U_Y(Y_t, C_t, C_{t-1}, e_t) = \lambda \tag{2.43}$$

$$U_1(Y_t, C_t, C_{t-1}, e_t) + \beta U_2(Y_{t+1}, C_{t+1}, C_t, e_{t+1}) = \lambda P_t. \tag{2.44}$$

Equation (2.43) implies that the marginal utility of income equals the marginal utility of wealth. Equation (2.44) implies that the present value of the marginal utility of current consumption equals the product of current price times the marginal utility of wealth. Next, Becker et al. assume that the utility function takes the quadratic form given by equation (2.29). They solve equations (2.43) and (2.44) to get the following demand equation:

$$C_t = \theta C_{t-1} + \beta\theta C_{t+1} + \theta_1 P_t + \theta_2 e_t + \theta_3 e_{t+1}. \tag{2.45}$$

Becker et al. use the above equation to operationalize and test some of the predictions of the Becker-Murphy rational addiction model. Specifically, they claim that the addictive nature of a good can be determined by looking at the sign of θ. If past consumption increases current consumption, θ will be positive in sign. In other words, the presence of an addictive good is supported by a positive θ. Another test of the rational addiction model is whether cigarette consumption is responsive to price. This can be determined by examining the coefficient of current price in equation (2.45). The rational addiction model predicts that the long-run elasticities of demand must exceed the short-run elasticities. The long-run elasticities can be computed for equation (2.45) in the same manner as in equations (2.34) and (2.37). Finally, note that equation (2.45) allows the researcher to test whether consumers are myopic or rational in their behavior. Myopic agents discount the future heavily. Thus, if myopia were present, one would expect to see a value of β close to zero. In other words, the coefficient of future consumption would not be significant in equation (2.45). This would give rise to an equation of the form:

$$C_t = \tilde{\theta} C_{t-1} + \tilde{\theta}_1 P_t + \tilde{\theta}_2 e_t . \tag{2.46}$$

On the other hand, the hypothesis of rationality would be supported by the presence of a positively significant coefficient on future consumption.

Becker et al. use statewide time-series data for the U.S. from 1955-1985. They incorporate the impact of health scares by using yearly dummy variables and use tax differentials among states to capture the effect of inter-state cigarette smuggling. They use instrumental variable methods to estimate equation (2.45) because the coefficients from ordinary least squares would be biased due to the endogeneity of C_{t-1} and C_{t+1}. They find that the estimated effects of past and future consumption on current consumption are significant and positive while the estimated current period price effects are negative. The authors also estimate equation (2.46). They find that cigarette smoking is negatively related to current price and positively related to past consumption. When a one period lead price is added and equation (2.46) is estimated by two stage least squares, the coefficient on the lead price turns out to be negative and significant. This shows that the data do not support a myopic model because variables from the future do play a role in current consumption decisions.

The empirical evidence according to Chaloupka and Becker et al. provides strong support for the rational addiction model. In addition, the rational model can generate myopic behavior as a sub case. Thus, any study dealing with an economic analysis of addictive goods should consider the contribution of the rational addiction model. The rational addiction model in its current form does not concentrate on generating non-addictive goods as a special case because that was never the purpose of this model. The next chapter extends the rational addiction model proposed by Becker et al. to provide a microeconomic basis for the sub case of non-addictive goods. It also considers the impact of addiction information on cigarette demand.

CHAPTER 3
THEORY

A Generalized Cigarette Demand Model with Addiction Information

The purpose of this chapter is to construct a model in which a single utility maximization problem can yield the demand for either an addictive good or a non-addictive good. Furthermore, this model will strive to predict changes in the behavior of consumers who are consuming addictive goods (without the explicit knowledge of the future consequences of current consumption) when they are informed of the addictive aspects of the good that they are consuming.

It is important to be able to test the hypothesis whether cigarettes are an addictive good because this has been matter of debate between the cigarette industry and the government. In addition to this, the impact of addiction information on consumption patterns of an addictive good warrants an investigation because of the policy implications of the potential sensitivity of consumption of such goods to this information. This chapter will begin with a general microeconomic model that establishes a single framework for the derivation of the demand for a good regardless of its addictive properties. Then, the sub cases of myopic and rational addictive demand will be explored to examine the impact of addiction information on consumers. Next, a summary of the testable implications produced by this model is presented. Finally, the chapter concludes with a solution to the difference equation generated by the theoretical model.

Generalizing the Rational Addiction Model: A Modified Stock Constraint

In recent studies such as Becker et al. (1994), the impact of an addictive good C_t on the agent's decision making process has been modeled by including a variable A_t, the addictive stock, as an argument of the utility function. Recall equation (2.17) in discrete form.

$$U_t = U(Y_t, C_t, A_t) \tag{3.1}$$

The addictive stock in a given period is equal to the sum of last period's consumption and the undepreciated portion of last period's addictive stock. This is evident from equation (2.42) which is reproduced here for convenience.

$$A_t = C_{t-1} + (1-\delta)A_{t-1} \tag{3.2}$$

It should be noted that in equation (3.2), even if δ, the depreciation rate of the addictive stock, is one-hundred percent, the addictive stock in any time period is still equal to last period's consumption level. In other words for δ=1, equation (3.2) reduces to:

$$A_t = C_{t-1}. \tag{3.3}$$

Note that Y_t, the non-addictive good, does not accrue an addictive stock.

The 1988 Surgeon General's Report points out that nicotine produces pleasurable sensations by accumulating in the brain soon after inhalation. The prolonged use of nicotine over time causes the body to be accustomed to a certain level of the drug. If the body experiences a drop in the level of nicotine below the level that it is used to, then the person experiences withdrawal. If nicotine did not accumulate in the brain and produce its pleasurable effects and cause subsequent bio-chemical dependence, one might argue that nicotine is not addictive. In an economic model of addiction, the parallel would be a good that did not accumulate an addictive stock.

Consider, the following addictive stock equation:

$$A_t = (1-\delta)C_{t-1} + (1-\delta)A_{t-1}. \tag{3.4}$$

Equation (3.4) states that A_t, the addictive stock at any point in time, is equal to $(1-\delta)C_{t-1}$, the undepreciated portion of last period's consumption, plus $(1-\delta)A_{t-1}$, the undepreciated portion of last period's addictive stock. The coefficient δ is the rate at which last period's consumption and the addictive stock decay. If the depreciation effects of the drug are complete and instantaneous (i.e., if $\delta=1$), then the addictive stock in period t will be zero even if the person consumed the substance in the last period. A non-addictive good is one that does not accumulate an addictive stock. Thus, one could model a non-addictive good as a special case of an addictive good with complete and instantaneous depreciation. This idea seems to be consistent with the medical facts of addiction. If nicotine is instantly removed from the body, it will not have the time to accumulate in the brain and produce pleasurable effects or the longer term effects of bio-chemical dependence.

Equation (3.4) is a first-order linear difference equation in A_t. Its solution is given by:

$$A_t = \sum_{i=0}^{t-1}(1-\delta)^{t-i}C_i + (1-\delta)^t A_0. \tag{3.5}$$

Equation (3.5) implies that the addictive stock at any point in time t is the sum of the undepreciated remnants of previous consumption plus the remaining undepreciated amount of the initial value of the addictive stock, A_0, that the person possesses at time zero. The details of the solution are contained in Appendix B. Given the assumption that the initial value of the addictive stock is zero, equation (3.5) reduces to:

$$A_t = \sum_{i=0}^{t-1} (1-\delta)^{t-i} C_i . \tag{3.6}$$

From equation (3.6) it is evident that for a depreciation rate less than one-hundred percent, past consumption contributes to the addictive stock. However, for the case of complete and instantaneous depreciation, the addictive stock is zero, giving rise to a good whose demand is independent of any habitual aspects. In other words, if a good is non-addictive, it has a depreciation rate of $\delta=1$. If on the other hand, the good is addictive, this would correspond to a depreciation rate of $\delta<1$. Thus, a simple modification of the addictive stock constraint allows one to model the demand for both addictive and non-addictive goods as sub cases of a more general model.

The Rational Agent's Utility Maximization Problem

The agent's utility function at any point in time is dependent on C_t, the agent's consumption of the addictive good; Y_t, the amount of the composite good; A_t, the stock of the addictive good; and e_t, other unobservable period t events that impact utility. The agent's period t utility function is represented by equation (3.7).

$$U_t = U(Y_t, C_t, A_t, e_t) \tag{3.7}$$

By assumption, $U_{Y_t} > 0$, $U_{C_t} > 0$ and $U_{A_t} < 0$. Marginal utility is assumed to increase with the consumption of the composite good and the consumption of the addictive good, while it is assumed to decrease with increases in the addictive stock. Thus, the model accounts for the presence of tolerance ($U_{A_t} < 0$) and withdrawal ($U_{C_t} > 0$). Tolerance refers to the effect of achieving a lower level of response from a given amount of the addictive substance as the level of past consumption rises. Withdrawal refers to the decline in utility from the reduction or cessation of consumption of the addictive good. Reinforcement refers to the increasing benefits from each additional unit of drug consumption as the agent's past experience with the substance increases. This is captured by assuming that $U_{C_t A_t} > 0$. The utility function is also assumed to be strictly concave in Y_t, C_t and A_t.

Next, assume a simplified version of the addictive stock constraint. In keeping with Becker et al., assume that only the previous period's consumption enters into the addictive stock. Thus, the simplified stock constraint is given by:

$$A_t = (1 - \delta)C_{t-1}. \tag{3.8}$$

Substituting out for A_t and using equation (3.8) in equation (3.7) yields:

$$U_t = U(Y_t, C_t, (1 - \delta)C_{t-1}, e_t). \tag{3.9}$$

Given that the agent lives for T years and discounts future utility at r, the rate of market interest, one can write the agent's lifetime utility function as:

$$U(0) = \sum_{t=1}^{T} \beta^{t-1} U(Y_t, C_t, (1-\delta)C_{t-1}, e_t) \tag{3.10}$$

where $\beta \equiv \frac{1}{(1+r)}$. β is the agent's discount factor.

The lifetime budget constraint is given by:

$$\sum_{t=1}^{T} \beta^{t-1}(Y_t + P_t C_t) = W_0. \tag{3.11}$$

W_0 is the present value of lifetime wealth, and the price of Y_t is one since Y_t is the numeraire. P_t is the price of the addictive good in period t. Equation (3.11) is based upon the assumption of the existence of perfect capital markets.

The consumer maximizes lifetime utility given by equation (3.10) subject to an initial value of consumption C^0 and the lifetime budget constraint given by equation (3.11). The Lagrangian for this problem can be written as:

$$L = \sum_{t=1}^{T} \beta^{t-1} U(Y_t, C_t, (1-\delta)C_{t-1}, e_t) + \lambda\{W_0 - \sum_{t=1}^{T} \beta^{t-1}(Y_t + P_t C_t)\}. \tag{3.12}$$

The resulting first order conditions with respect to Y_t and C_t are:

$$U_{Y_t}(Y_t, C_t, (1-\delta)C_{t-1}, e_t) = \lambda \tag{3.13}$$

$$U_1(Y_t, C_t, (1-\delta)C_{t-1}, e_t) + \beta(1-\delta)U_2(Y_{t+1}, C_{t+1}, (1-\delta)C_t, e_{t+1}) = \lambda P_t. \tag{3.14}$$

The first order conditions can be interpreted as follows. Equation (3.13) states that the marginal utility from consuming the composite good is equal to the shadow price λ, which itself is the marginal utility of wealth. λ is assumed to be constant. Thus, the demand equation derived from the first order conditions (3.13) and (3.14) holds the marginal utility of wealth constant. Equation (3.14) states that the present value of the marginal utility of current consumption equals the product of current price multiplied by the marginal utility of wealth. The rational addict not only considers the impact of current consumption on this period's marginal utility but also its impact on next period's utility through its contribution towards next period's addictive stock. It is interesting to note that when there is no depreciation in the model (i.e., δ=0), the resulting first order conditions are identical to those of Becker et al. given by equations (2.43) and (2.44). Furthermore, when δ=1, the first order conditions given by equations (3.13) and (3.14), respectively, are independent of C_{t-1}, the past value of consumption. Thus, for the case of $\delta=1$, equations (3.13) and (3.14) yield the first order conditions from the dynamic utility maximization problem of a non-addictive good. Hence, one can model the demand for both addictive and non-addictive goods as sub cases of the same time consistent utility maximization problem. This approach eliminates the need for specifying different utility functions for the same agent in order to model her consumption of both types of goods. In the next section a specific demand function is derived using a quadratic utility function.

Deriving a Generalized Rational Addiction Demand Equation

The utility function is assumed to be quadratic in C_t, this period's consumption; A_t, the addictive stock; Y_t, the composite good; and e_t, the unobservable life-cycle events. This function is given by equation (3.15).

$$U_t = U_1C_t + U_2A_t + U_yY_t + U_ee_t + \frac{U_{11}}{2}C_t^2 + \frac{U_{22}}{2}A_t^2 + \frac{U_{yy}}{2}Y_t^2 + \frac{U_{ee}}{2}e_t^2$$
$$+U_{12}C_tA_t + U_{1y}C_tY_t + U_{1e}C_te_t + U_{2y}A_tY_t + U_{2e}A_te_t + U_{ye}Y_te_t \tag{3.15}$$

Next, substitute out for A_t using equation (3.8). This yields the following instantaneous quadratic utility function:

$$U_t = U_1C_t + U_2(1-\delta)C_{t-1} + U_yY_t + U_ee_t + \frac{U_{11}}{2}C_t^2 + \frac{U_{22}}{2}(1-\delta)^2C_{t-1}^2$$

$$+\frac{U_{yy}}{2}Y_t^2 + \frac{U_{ee}}{2}e_t^2 + U_{12}C_t(1-\delta)C_{t-1} + U_{1y}C_tY_t + U_{1e}C_te_t$$

$$+U_{2y}(1-\delta)C_{t-1}Y_t + U_{2e}(1-\delta)C_{t-1}e_t + U_{ye}Y_te_t. \quad (3.16)$$

One can use the specific utility function given by equation (3.16) to determine the exact form that the first order conditions given by equations (3.13) and (3.14) will take. The first order conditions that correspond to the quadratic utility function specified in equation (3.16) are:

$$U_y + U_{yy}Y_t + U_{1y}C_t + U_{2y}(1-\delta)C_{t-1} + U_{ye}e_t = \lambda \quad (3.17)$$

$$[U_1 + U_{11}C_t + U_{12}(1-\delta)C_{t-1} + U_{1y}Y_t + U_{1e}e_t]$$

$$+\beta[U_2(1-\delta) + U_{22}(1-\delta)^2C_t + U_{12}(1-\delta)C_{t+1} + U_{2y}(1-\delta)Y_{t+1}$$

$$+U_{2e}(1-\delta)e_{t+1}] = \lambda P_t. \quad (3.18)$$

In keeping with Becker et al., solve equation (3.17) for Y_t. The expression for Y_t is given by equation (3.19).

$$Y_t = \frac{[\lambda - U_y - U_{1y}C_t - U_{2y}(1-\delta)C_{t-1} - U_{ye}e_t]}{U_{yy}} \quad (3.19)$$

Next, using equation (3.19), substitute out for Y_t and Y_{t+1} in equation (3.18). Then solve for C_t. The resulting expression for C_t is given by equation (3.20).

$$C_t = \alpha_0 + \alpha_1C_{t-1} + \alpha_2C_{t+1} + \alpha_3P_t + \alpha_4e_t + \alpha_5e_{t+1} \quad (3.20)$$

The α coefficients in equation (3.20) are defined as follows:

$$\alpha_0 = \frac{\left[-U_1 - U_{1y}\dfrac{(\lambda - U_y)}{U_{yy}} - \beta U_2(1-\delta) - \beta U_{2y}\dfrac{(1-\delta)(\lambda - U_y)}{U_{yy}}\right]}{\Omega}. \tag{3.21}$$

$$\alpha_1 = \frac{1}{\Omega}[-U_{12}(1-\delta) + \frac{U_{1y}U_{2y}(1-\delta)}{U_{yy}}]. \tag{3.22}$$

$$\alpha_2 = \frac{1}{\Omega}[-\beta U_{12}(1-\delta) + \frac{\beta U_{1y}U_{2y}(1-\delta)}{U_{yy}}]. \tag{3.23}$$

$$\alpha_3 = \frac{\lambda}{\Omega}. \tag{3.24}$$

$$\alpha_4 = \frac{1}{\Omega}[\frac{U_{1y}U_{ye}}{U_{yy}} - U_{1e}]. \tag{3.25}$$

$$\alpha_5 = \frac{1}{\Omega}[\frac{\beta U_{2y}U_{ye}(1-\delta)}{U_{yy}} - \beta U_{2e}(1-\delta)]. \tag{3.26}$$

where

$$\Omega = [U_{11} - \frac{U_{1y}^2}{U_{yy}} + \beta U_{22}(1-\delta)^2 - \frac{\beta U_{2y}^2(1-\delta)^2}{U_{yy}}]. \tag{3.27}$$

The demand function given by equation (3.20) has a very generalized form. It can generate the demand for non-addictive goods as a special case with $\delta=1$. In the event that $\delta=0$ and the intercept is suppressed, equation (3.20) reduces to the rational addiction demand equation derived by Becker et al. because they suppress the intercept in their theoretical model. This is another difference between their model and equation (3.20).

Addictive versus Non-Addictive Goods

Consider equation (3.20) for the special case that $\delta=1$. This is the case of complete and instantaneous depletion of the addictive stock. In this case $\alpha_1=\alpha_2=\alpha_5=0$. Thus, equation (3.20) reduces to equation (3.28).

$$C_t = \tilde{\alpha}_0 + \tilde{\alpha}_3 P_t + \tilde{\alpha}_4 e_t \tag{3.28}$$

Equation (3.28) states that in the case of complete and instantaneous depreciation, the dynamic demand equation for the good is independent of past consumption. In other words, the model yields a demand equation for a non-addictive good as a special case of the generalized model for addictive goods. If $\delta<1$, then the addictive stock does not decay completely, and the demand for the addictive good is given by equation (3.20). Current microeconomic models require separate utility maximization problems to be specified in order to derive the demand for both addictive and non-addictive goods. This model provides a single utility maximization problem for the derivation of an agent's demand functions regardless of the addictive nature of the good. In addition, the addictive sub case of this approach does not sacrifice the ability of the model to distinguish between myopic and rational consumption patterns.

The Impact of Addiction Information on Cigarette Demand

It is the premise of this dissertation that the revelation of addiction information about a particular good serves to make consumers aware of the implications of current consumption decisions for future choices and, consequently, on future utility levels. In the absence of addiction information about a good that is addictive, consumers have to rely on their past consumption experience of the good. They adjust their current consumption levels to maximize current utility while compensating for the effects of tolerance, reinforcement and withdrawal due to past consumption. However, consumers do not account explicitly for the effects of present consumption on future utility until they are informed that the good is addictive. In other words, consumers carry out a one-period utility maximization process subject to an addictive stock constraint and a one-period budget constraint. When consumers are explicitly made aware of the future consequences of current consumption, it is then that they adjust their current consumption levels to be consistent with a forward looking multi-period utility maximization process subject to an addictive stock constraint and a lifetime budget constraint. The next sub-section considers the demand for an addictive good by a consumer that is not explicitly aware of the addictive nature of the good. Then the demand functions of an informed and an uninformed agent are compared and contrasted.

Myopic vs. Rational Behavior

The reasoning behind myopic models of addiction as summarized by Becker et al. is that agents have a higher rate of time preference for the present and, thus, tend to ignore the future implications of current consumption. However, Becker et al. theorize that agents are forward looking and do consider the future effects of consuming an addictive good. Their empirical findings and those of Chaloupka support this notion.

The competing myopic and rational models of addiction can be reconciled under a framework that considers the nature of addiction information available to agents. In this study, agents are hypothesized to exhibit myopic behavior in the consumption of addictive goods when they are not explicitly informed of the addictive properties of the good. Once they are told about the addictive nature of the good, agents are hypothesized to consider the future implications of current consumption. It is now appropriate to demonstrate that the current theoretical model retains the ability of the Becker et al. model to nest a myopic model of addiction within the rational model.

Myopic or Uninformed Demand

Consider a forward looking agent who is consuming an addictive good without the explicit information about the effects of current consumption on future utility. The relevant optimization procedure is the following one period static utility maximization model:

$$\max_{C_t, Y_t} U(C_t, A_t, Y_t, e_t)$$

$$\text{subject to } A_t = Y_t + P_t C_t \text{ and } A_t = (1-\delta)C_{t-1}. \tag{3.29}$$

The Lagrangian for this myopic maximization problem is given by:

$$L = U(C_t, (1-\delta)C_{t-1}, Y_t, e_t) + \lambda\{A_t - Y_t - P_t C_t\}. \tag{3.30}$$

The associated first order conditions are:

$$U_{Y_t}(C_t, (1-\delta)C_{t-1}, Y_t, e_t) = \lambda \tag{3.31}$$

$$U_{C_t}(C_t, (1-\delta)C_{t-1}, Y_t, e_t) = \lambda P_t. \tag{3.32}$$

Given the quadratic utility function expressed in equation (3.16), equations (3.31) and (3.32) can be solved in the same way as equations (3.17) and (3.18) to yield the following myopic demand function:

$$C_t = \theta_0 + \theta_1 C_{t-1} + \theta_2 P_t + \theta_3 e_t. \tag{3.33}$$

The θ coefficients are defined as:

$$\theta_0 = \frac{-[U_1 U_{yy} + U_{1y}(\lambda - U_y)]}{[U_{11} U_{yy} - U_{1y}^2]}. \tag{3.34}$$

$$\theta_1 = \frac{-(1-\delta)[U_{12}U_{yy} - U_{1y}U_{2y}]}{[U_{11}U_{yy} - U_{1y}^2]}. \tag{3.35}$$

$$\theta_2 = \frac{\lambda U_{yy}}{[U_{11}U_{yy} - U_{1y}^2]}. \tag{3.36}$$

$$\theta_3 = \frac{-[U_{1e}U_{yy} - U_{1y}U_{ye}]}{[U_{11}U_{yy} - U_{1y}^2]}. \tag{3.37}$$

If δ=0 and the intercept is suppressed, equation (3.33) coincides with the Becker et al. version of a myopic demand function for an addictive good. The motivation for the Becker et al. version of the myopic model is that it is a sub case of the rational addiction model given an agent with a very high rate of time preference for the present (i.e., β=0). On the other hand, the version of the rational addiction model in this dissertation posits that even agents with a low rate of time preference for the present will exhibit myopic consumption behavior unless they are explicitly informed about the future implications of current consumption of the addictive good. In fact, one can argue that a disclosure of information about the addictive properties of a good will prompt a switch in the pattern of consumption precisely because agents become forward looking. When agents become aware of the future implications of current consumption of the addictive good, they will adjust their consumption patterns to maximize their utility over several future time periods resulting in a switch from a myopic to a rational pattern of consumption. The current model can also be used to predict changes in the magnitude of coefficients of the demand equation. The next sub-section examines the magnitude and direction of the changes in the coefficients of the demand equation following the dissemination of addiction information.

Testable Implications of the Theory

A switch from a myopic to a rational demand function following the release of addiction information is posited in this work. This hypothesis yields the following testable implications. Prior to the release of addiction information, demand should take the myopic form indicated in equation (3.33); and after the information is released, the demand function we observe should resemble the rational demand function in equation (3.20). In other words, when agents are unaware of the future consequences of consuming an addictive good, their current quantity demanded is independent of future consumption. However, when agents are aware of the additive nature of a good then current and future consumption decisions are linked together.

In order to examine the direction and the magnitude of the changes of the coefficients when agents switch from a myopic to a rational regime, it is useful to compare and contrast the corresponding coefficients from equations (3.20) and (3.33). In keeping with Chaloupka (1991), it is assumed that the amount of the addictive good consumed and the amount of the addictive stock do not affect the marginal utility of the composite good. In other words:

$$U_{1y} = U_{2y} = 0. \tag{3.38}$$

The Influence of Past Consumption on Present Consumption

Using equation (3.38) and (3.27) to simplify equations (3.22) and (3.35), respectively, yields:

$$\alpha_1 = \frac{\overset{(+)}{-U_{12}}\,\overset{(+)}{(1-\delta)}}{\underset{(-)}{U_{11}} + \underset{(+)}{\beta}\,\underset{(-)}{U_{22}}\,\underset{(+)}{(1-\delta)^2}} > 0 \tag{3.39}$$

$$\theta_1 = \frac{\overset{(+)}{-U_{12}}\,\overset{(+)}{(1-\delta)}}{\underset{(-)}{U_{11}}} > 0. \tag{3.40}$$

A comparison of (3.39) and (3.40) shows that θ_1 is greater than α_1. In other words, after the release of addiction information when agents switch from myopic to rational consumption patterns, the ability of a unit of last period's consumption to increase this period's consumption declines.

The Influence of Future Consumption on Current Consumption

In a myopic model the effect of next period's consumption on current consumption is nil because in a myopic model agents do not consider the future effects of current consumption. In a rational model, however, future consumption does influence current consumption. In keeping with Becker et al., the model developed in this paper predicts that current and future consumption will be adjacent complements. This can be seen by examining the sign of the coefficient on future consumption in equation (3.23). Using equation (3.38) to simplify equation (3.23) yields:

$$\alpha_2 = \frac{-\overset{(+)}{\beta}\,\overset{(+)}{U_{12}}\,\overset{(+)}{(1-\delta)}}{\underset{(-)}{U_{11}} + \underset{(+)}{\beta}\,\underset{(-)}{U_{22}}\,\underset{(+)}{(1-\delta)^2}} > 0. \tag{3.41}$$

The Influence of Price on Present Consumption

Once again, use equation (3.38) and (3.27) to simplify the coefficients of price in the myopic and rational demand equations given by equations (3.36) and (3.24), respectively. The simplified expressions for these coefficients are given by:

$$\theta_2 = \frac{\overset{(+)}{\lambda}}{\underset{(-)}{U_{11}}} < 0 \tag{3.42}$$

$$\alpha_3 = \frac{\overset{(+)}{\lambda}}{\underset{(-)}{U_{11}} + \underset{(+)}{\beta}\ \underset{(-)}{U_{22}}\ \underset{(+)}{(1-\delta)^2}} < 0. \tag{3.43}$$

A comparison of equations (3.42) and (3.43) shows that in absolute value θ_2 exceeds α_3. The model predicts that the release of addiction information which prompts consumption patterns to switch from myopic to rational causes a dampening of the effect of current price on current quantity demanded. This result can be interpreted in terms of elasticities. The current period own-price elasticity at the means is defined by:

$$\varepsilon = \frac{\partial C_t}{\partial P_t} * \frac{\overline{P_t}}{\overline{C_t}}, \tag{3.44}$$

where $\overline{P_t}$ and $\overline{C_t}$ are the average current period price and quantity, respectively. Because θ_2 exceeds α_3 in absolute value and using equation (3.44), it can be shown that the current period own price elasticity at the mean for a myopic agent exceeds that of an otherwise identical rational agent in absolute value given that C_t is the same in both cases.

$$\varepsilon_{MYOPIC} = \left|\frac{\partial C_t}{\partial P_t} * \frac{\overline{P_t}}{\overline{C_t}}\right| = \left|\theta_2 * \frac{\overline{P_t}}{\overline{C_t}}\right| > \left|\alpha_3 * \frac{\overline{P_t}}{\overline{C_t}}\right| = \left|\frac{\partial C_t}{\partial P_t} * \frac{\overline{P_t}}{\overline{C_t}}\right| = \varepsilon_{RATIONAL} \tag{3.45}$$

Simulating Consumption via the Demand Equation

Another contribution of the theoretical model derived in this study is that it presents an avenue to simulate past, current and future consumption using the solution to the difference equation given by (3.20). This equation is a second-order difference equation in C_t. The temporal nature of this equation becomes evident when it is manipulated to rotate all terms containing C to the left-hand side and is recursed back by one time period. This is done in equation (3.46).

$$C_{t-1} - \alpha_1 C_{t-2} - \alpha_2 C_t = \alpha_0 + \alpha_3 P_{t-1} + \alpha_4 e_{t-1} + \alpha_5 e_t \qquad (3.46)$$

The general solution to equation (3.46) is given by equation (3.47).

$$C_t = A_1\phi_1^t + A_2\phi_2^t + \frac{1}{\alpha_1\phi_2(\phi_2 - \phi_1)}\sum_{j=0}^{\infty}\phi_2^{-j}h(t-j) + \frac{1}{\alpha_1\phi_1(\phi_2 - \phi_1)}\sum_{j=1}^{\infty}\phi_1^{j}h(t+j)\,. \qquad (3.47)$$

ϕ_1 and ϕ_2 are the roots of the homogeneous version of equation (3.46), A_1 and A_2 are constants that are to be determined using initial conditions, C^0 is the initial value of consumption and h(t) is an abbreviation for the exogenous variables on the right-hand side of equation (3.46). The details of solving equation (3.46) to obtain equation (3.47) are presented in Appendix C. The expressions for ϕ_1, ϕ_2 and h(t) are given by equations (3.48), (3.49) and (3.50), respectively.

$$\phi_1 = \frac{1 - \sqrt{1 - 4\alpha_1\alpha_2}}{2\alpha_1} \qquad (3.48)$$

$$\phi_2 = \frac{1 + \sqrt{1 - 4\alpha_1\alpha_2}}{2\alpha_1} \qquad (3.49)$$

$$h(t) \equiv \alpha_0 + \alpha_3 P_{t-1} + \alpha_4 e_{t-1} + \alpha_5 e_t \tag{3.50}$$

It should be noted that the general solution presented in equation (3.47) yields the complete solution to the difference equation derived in this study only under the following specific assumptions.

$$A_2 = 0 \tag{3.51}$$

$$h(-s) = 0 \;\; \forall \;\; s > 0 \tag{3.52}$$

One can use equations (3.50), (3.51) and (3.52) to manipulate equation (3.47) to obtain equation (3.53).

$$C_t = \left(C^0 - \frac{1}{\alpha_1 \phi_1 (\phi_2 - \phi_1)} \sum_{j=1}^{\infty} \phi_1^{j} h(j) \right) \phi_1^{t} + \frac{1}{\alpha_1 \phi_2 (\phi_2 - \phi_1)} \sum_{j=0}^{t} \phi_2^{-j} h(t-j)$$

$$+ \frac{1}{\alpha_1 \phi_1 (\phi_2 - \phi_1)} \sum_{j=1}^{\infty} \phi_1^{j} h(t+j) \tag{3.53}$$

Equation (3.53) is the complete solution to the difference equation given by equation (3.46). The details of deriving equation (3.53) from equation (3.46) are also contained in Appendix C. The solution to the difference equation is a function of the truly exogenous variables in the model developed in this study. It can be used to simulate the impact of addiction information on cigarette consumption. The parameters in equation (3.53) can be calculated by using the coefficients of the demand equation (3.46). The solution given by equation (3.53) yields the Becker et al. solution to equation (3.53) only under a further specific assumption. The derivation of the Becker et al. solution as a sub case of equation (3.53) is described in detail in Appendix C.

CHAPTER 4.
METHODOLOGY

The purpose of this chapter is to construct an empirical model that operationalizes the theory. The first section of this chapter outlines an empirically estimable demand equation that allows for structural shifts in both the slope and the intercept coefficients of the demand function. Next, the issue of cigarette smuggling and its impact on the demand for cigarettes will be discussed. The demand equation will be modified to account for the impact of smuggling variables. Then the focus shifts to a detailed description of the data set and construction of the variables. The next section discusses the relevant econometric procedures. Finally, the chapter concludes with a summary of the expected signs of the estimated coefficients in the demand equation.

Econometric Implementation of Structural Shift

One of the main objectives of this model is to test whether the release of addiction information in 1979 impacted the pattern of cigarette consumption in any significant way. In this study it is hypothesized that in the absence of addiction information, agents will exhibit myopic consumption patterns. However, once they are given information on the addictive properties of the good, they will switch to rational patterns of consumption. As explained in the previous chapter, such a switch in consumption patterns is evidenced by a change in the magnitude of the coefficients of past consumption, future consumption and price in the demand equation. Moreover, this switch in consumption patterns implies that future consumption becomes a significant variable in the post-information demand function. For the reader's convenience the myopic demand function from equation (3.33) and the rational demand function from equation (3.20) are reproduced here as equations (4.1) and (4.2).

$$C_t = \theta_0 + \theta_1 C_{t-1} + \theta_2 P_t + \theta_3 e_t \tag{4.1}$$

$$C_t = \alpha_0 + \alpha_1 C_{t-1} + \alpha_2 C_{t+1} + \alpha_3 P_t + \alpha_4 e_t + \alpha_5 e_{t+1} \tag{4.2}$$

Because myopic demand is a sub case of the rational addiction demand function, one can operationalize the hypothesized structural changes in the demand function by specifying a regression equation which allows one to model the changes in the magnitudes of the coefficients of the rational addiction demand function. This is done by modifying equation (3.20) to include a dummy variable INFO which, if significant, will alter the magnitudes of the post-information era regression coefficients. INFO takes on a value of zero for any year prior to 1979 and a value of one for the years 1979 and beyond. This modified specification is given by equation (4.3):

$$C_t = \eta_0 + (\eta_1 + \gamma_1 \text{INFO})C_{t-1} + (\eta_2 + \gamma_2 \text{INFO})C_{t+1} + (\eta_3 + \gamma_3 \text{INFO})P_t + \varepsilon_t . \tag{4.3}$$

The operationalization of equation (4.2) can be explained succinctly if the right hand side of equation (4.3) is multiplied out.

$$C_t = \eta_0 + \eta_1 C_{t-1} + \gamma_1(\text{INFO} * C_{t-1}) + \eta_2 C_{t+1} + \gamma_2(\text{INFO} * C_{t+1})$$
$$+ \eta_3 P_t + \gamma_3(\text{INFO} * P_t) + \varepsilon_t \tag{4.4}$$

In equation (4.4) the impact of each right hand side variable is split into two parts. The η's show the impact of the variable on consumption prior to the release of addiction information and the sum of the corresponding η's and γ's show the impact of the same variables after the release of addiction information. ε is the error term generated by the absence of the unobservables e_t and e_{t+1} in the regression equation. The predicted signs of the

γ's will be inferred based upon the hypothesis of a switch from a myopic to a rational model. The pre-information and post-information coefficients are summarized in Table 4.1.

A switch from a myopic demand function of the form depicted in equation (4.1) to a rational demand function shown in equation (4.2) has the following implications for the γ's. According to equations (3.39) and (3.40) θ_1 is greater than α_1. Hence, the predicted sign of γ_1 is negative. Similarly, from equations (3.42) and (3.43) it is apparent that α_3 exceeds θ_2. Thus, the predicted sign of γ_3 is positive. Finally, since C_{t-1} is not included in the myopic model its coefficient in the pre-information years is zero. In other words, if the hypothesis of myopia in the pre-information era is accurate, η_2 in equation (4.4) will not be significantly different from zero. However, in the post-information years the coefficient of C_{t-1} ($\eta_2 + \gamma_2$) in the rational demand equation is predicted to be positive. This prediction is based on equation (3.41) where α_2 is signed positive. Hence, in the post-information years the predicted sign of γ_2 is positive.

Table 4.1. Pre-information and Post-information Coefficients

Variable	Pre-information Coefficient	Post-information Coefficient
C_{t-1}	$\eta_1 = \theta_1$	$\eta_1 + \gamma_1 = \alpha_1$
C_{t+1}	η_2	$\eta_2 + \gamma_2 = \alpha_2$
P_t	$\eta_3 = \theta_2$	$\eta_3 + \gamma_3 = \alpha_3$

A summary of the expected signs of these is given in Table 4.4 which appears at the end of this chapter. A discussion of the constant term will be presented after a description of the data. Next, equation (4.2) will be modified to control for the effects of interstate cigarette smuggling.

Adjusting for Interstate Smuggling Bias

This purpose of this paper is to estimate the impact of addiction information on consumers across the United States. Hence, the data set, which will be described in detail in the next section, is comprised of annual time-series data for the fifty states and the District of Columbia in the United States. Per capita consumption is measured by annual per capita sales in each state given by the number of packs sold. Cigarette prices are given by average retail prices per pack. These prices are inclusive of state and federal taxes. As a result of significant differences in state excise taxes, there is a financial incentive to smuggle cigarettes from lower-tax states to higher-tax states for resale or consumption. Since per capita consumption is proxied by per capita cigarette sales, it is important to account for the impact of interstate smuggling on per capita cigarette sales. A failure to do so would result in states with low cigarette excise taxes having overstated per capita consumption and states with high cigarette excise taxes having understated per capita cigarette consumption. According to Greene (1997), the omission of relevant smuggling variables which are correlated with state excise taxes that are contained in average retail prices will lead to biased and inconsistent parameter estimates.

In order to construct proxies that capture the effects of interstate cigarette smuggling, it is useful to briefly describe the incentives for the different types of cigarette smuggling that exist. Becker et al. (1994) mention two different types of smuggling: short-distance and long-distance smuggling. Short-distance smuggling refers to the actions of cigarette consumers who live in high-tax states but purchase cigarettes in neighboring lower-tax states for consumption at home. This type of smuggling is only convenient for consumers who live sufficiently close to the border of one or more low-tax states. The behavior of these agents has also been referred to as "casual smuggling" by Thursby and Thursby (1994). Becker et al. also describe a more organized smuggling effort which they term "long-distance smuggling." This refers to the practice of organized attempts by distributors to purchase cigarettes in the low-tax states of Virginia, North Carolina and Kentucky and ship these cigarettes to other states where they are sold at existing retail prices. Thursby and Thursby refer to this as "commercial smuggling." They provide an analysis of the economic incentives that motivate commercial smuggling. Cigarette distributors legally purchase tax-paid cigarettes in one or more of the aforementioned low-tax states. Then they bribe the wholesaler in the low-tax state not to affix the local tax indicia. Next, they arrange for the cigarettes to be smuggled into various high-tax states where the cigarettes are tagged with counterfeit indicia for payment of state taxes which are never made. Finally, they sell these cigarettes at the local prices prevailing in the higher-taxed states. Becker et al. devise different proxies for both short and long-distance smuggling. Because the data set used in this study is quite similar to theirs, a detailed description of their smuggling proxy variables is in order.

Becker et al. proxy casual or short-distance smuggling using two different indices: SDTIMP and SDTEXP. SDTIMP for the ith state is defined as:

$$SDTIMP_i = \sum_j k_{ij}(T_i - T_j) \tag{4.5}$$

In equation (4.5) state i is the state with the higher state tax rate, and state j is any bordering state with a lower cigarette excise tax. SDTIMP proxies the incentive for agents in a higher-tax state to cross the border and purchase cigarettes in a reasonably close lower-tax state. Note that the summation is only taken over neighboring states with lower cigarette excise taxes than the home state. k_{ij} is the ratio of the number of people living in the higher-tax state (state i) within a distance of twenty miles of the lower-tax state (state j) to the total population of the higher-tax state (state i). These weights were computed from the 1995 TIGER/Line CD Bureau of the Census (1995). T_i is the real state cigarette excise tax per pack in the higher-tax state, and T_j is the real state cigarette excise tax per pack in the lower-tax state. These tax rates are taken from The Tax Burden on Tobacco, Tobacco Tax Council (1996). The sign of the variable SDTIMP is predicted to be negative when included in the regression equation (4.4) because as the positive tax differential between the home state and any lower-tax neighboring state grows, more consumers find it worth their time to cross the state line to purchase cigarettes. Thus, the per capita sales in the high-tax state will fall. Per capita consumption in the high-tax state may stay the same but more of the cigarettes consumed will be purchased across the border. Hence, the variable SDTIMP is included in the regression equation to control for these effects.

The incentives for a lower-tax state to be a casual exporter of cigarettes are captured by the variable SDTEXP.

$$SDTEXP_i = \sum_j k_{ji}(T_i - T_j)POP_j / POP_i \qquad (4.6)$$

In equation (4.6) state j is the higher-tax state, state i is the lower-tax state, and k_{ji} is the ratio of the number of people living in the higher-tax state (state j) within twenty miles of state i to the total population of state j. These ratios were also computed from the 1995 Current Population Reports. Note that the summation is only taken over neighboring states with higher cigarette excise taxes than the home state. T_j is the state cigarette excise tax per pack in the higher-tax state, and T_i is the state cigarette excise tax per pack in the lower-tax state. The border weights are multiplied by the ratio of POP_j, the total population of the people in the higher-tax state, to POP_i, the population of the people in the lower-tax state. The product of k_{ji} and (POP_j/POP_i) results in a ratio which expresses the population of the higher-tax state that lives within twenty miles of the lower-tax state as a fraction of the lower-tax state's total population. The reasoning behind this weighting scheme is as follows. Ceteris paribus, a larger border population in the high-tax state would potentially mean that more consumers would cross the border and purchase cigarettes in the low-tax state. Thus, the fraction of per capita sales in a low-tax state attributable to across the border customers would move in the same direction as the across the border population. However, a larger home population in the low-tax state might mean that a larger fraction of low-tax state per capita sales were attributable to purchases by low-tax state residents. Thus, in order to compensate for these competing effects, the tax differential between the two states is weighted by the ratio of the across the border twenty mile population of the high-tax state to the population of the low-tax state. The sign of the variable SDTEXP is predicted to be negative when included in regression equation (4.4) because the across the border sales (and hence, per capita sales in the lower-tax state) will increase as the tax difference gets larger. However, the reason for the negative sign is that this tax difference is expressed as a negative number. Ceteris paribus, as the higher-tax state's tax rate increases or its border population increases, the fraction of per capita sales in the lower-tax state attributable to non-resident purchases increases. Hence, the variable SDTEXP is included in the regression equation to compensate for these effects.

Becker et al. proxy the effects of long-distance smuggling on per capita sales via a single index which picks up both commercial export and commercial import effects. Commercial smuggling is done by cigarette sellers, and this is why purchase decisions by consumers in high-tax states are independent of the tax differentials between their home state and the long-distance exporting states of Kentucky, Virginia and North Carolina. This index LDTAX is defined differently for the three states.

Commercial smuggling is undertaken for profit motives. Becker et al. assume that it is only profitable to smuggle cigarettes into states that are within one thousand miles of

Kentucky, Virginia or North Carolina. States that are more than a thousand miles from Kentucky, Virginia or North Carolina are assumed not to engage in commercial smuggling. In other words, for states that are more than a thousand miles away from Kentucky, Virginia and North Carolina, the variable LDTAX takes a value of zero. In addition to this, Becker et al. assume that all states that lie to the west of Kentucky with a higher cigarette excise tax rate than Kentucky and within a thousand miles smuggle cigarettes in from Kentucky. This assumption makes sense because, of the three states, Kentucky lies farthest to the west. Table 4.2 gives a detailed list of states that are recipients of cigarettes that are smuggled in from Kentucky and Virginia and North Carolina. The expression for LDTAX for the western states within a thousand miles of Kentucky is given by equation (4.7).

$$LDTAX_i = (T_i - T_{KY}) \tag{4.7}$$

Hence, the incentive for the ith western state to smuggle cigarettes in from Kentucky is proxied by the difference between the cigarette excise tax in state i and the cigarette excise tax in Kentucky of the year in question. The predicted sign of LDTAX in equation (4.7) is negative for the following reasons. Ceteris paribus, as the tax differential widens, more and more cigarettes will be smuggled into state i from Kentucky, and the share of domestic sales in per capita consumption in state i will decline. If the tax rate in state i is lower than the tax rate in Kentucky, it is assumed that no cigarettes are imported from Kentucky, and LDTAX is set to zero for that state.

Becker et al. also assume that Virginia and North Carolina share the amount of cigarettes that are commercially smuggled into all states that lie to their northeast and southeast and are also within five hundred miles of North Carolina and Virginia. The expression for the LDTAX variable for these states is given by equation (4.8).

Table 4.2 Recipients of Commercially Smuggled Cigarettes

Kentucky Importers	Virginia and North Carolina Importers
Arkansas	Alabama
Illinois	Connecticut
Iowa	Delaware
Kansas	Florida
Louisiana	Georgia
Michigan	Indiana
Minnesota	Maryland
Missouri	Massachusetts
Nebraska	Mississippi
Oklahoma	New Hampshire
Wisconsin	New Jersey
	New York
	Ohio
	Pennsylvania
	Rhode Island
	South Carolina
	Tennessee
	Vermont
	Washington D.C.
	West Virginia

$$LDTAX_i = Z_{NC}(T_i - T_{NC}) + Z_{VA}(T_i - T_{VA}) \quad (4.8)$$

Equation (4.8) indicates that in any state i with a higher tax rate than either North Carolina or Virginia or both smuggling occurs from either one or both states . If the tax rate in state i is lower than the tax rate in an exporting state (i.e., North Carolina or Virginia), it is assumed that no cigarettes are imported from that state, and the tax differential between state i and the exporting state is set to zero. The proportion of the cigarettes smuggled in from either North Carolina or Virginia into state i is proxied by the sum of the weighted tax differentials between the cigarette excise taxes in state i and those of North Carolina and Virginia, respectively. The weights Z_{NC} and Z_{VA} are given by equations (4.9) and (4.10), respectively.

$$Z_{NC} = \frac{(\text{Value added in NC})}{(\text{Value added in NC} + \text{Value added in VA})} \quad (4.9)$$

$$Z_{VA} = \frac{(\text{Value added in VA})}{(\text{Value added in NC} + \text{Value added in VA})} \quad (4.10)$$

These weights are the ratios of the value-added from tobacco produced in each state to the sum of the value-added from tobacco production in both states. The value-added from tobacco production in each state was determined by taking an average over the years 1955-1964. Data for these years were obtained from the 1994 U.S. Tobacco Statistics (Creek, Capehart and Grise, 1994). Data for later years were not available. Once again the sign of the variable of LDTAX is predicted to be negative for reasons similar to those discussed previously. Ceteris paribus, as the tax differential widens, more and more cigarettes will be smuggled into state i from North Carolina and/or Virginia and the share of domestic sales in per capita consumption in state i will decline.

It is now time to examine how to account for the impact of commercial smuggling activities on the per capita sales of the states of Kentucky, Virginia and North Carolina. The LDTAX variable is also used to adjust per capita sales in Kentucky to reflect that a certain proportion of in state purchases are actually smuggled across the border and are not consumed in the state of Kentucky. The expression for LDTAX for the state of Kentucky is given by equation (4.11).

$$LDTAX_{KY} = \sum_{j}(T_{KY} - T_{j})\frac{POP_{j}}{POP_{KY}} \tag{4.11}$$

Note that the summation is taken over all potential importing states j that have a higher cigarette excise tax than Kentucky. The tax differential between Kentucky and state j is weighted by the ratio of the population of state j to that of Kentucky. This is presumably because a larger tax differential will prompt more commercial smuggling of cigarettes from Kentucky to state j. A larger population of state j (POP_j) will perhaps lead to a larger market for smugglers to cater to while, ceteris paribus, a larger population of the state of Kentucky (POP_{KY}) might mean that a larger fraction of per capita Kentucky cigarette sales are actually consumed in Kentucky.

The LDTAX variable for North Carolina and Virginia is calculated in a very similar fashion to that of Kentucky. The formulas for the computation of the LDTAX variable for the state of North Carolina and Virginia are given by equations (4.12) and (4.13).

$$LDTAX_{NC} = Z_{NC}\left[\sum_{j}(T_{NC} - T_{j})\frac{POP_{j}}{POP_{NC}}\right] \tag{4.12}$$

$$LDTAX_{VA} = Z_{VA}\left[\sum_{j}(T_{VA} - T_{j})\frac{POP_{j}}{POP_{VA}}\right] \tag{4.13}$$

Equations (4.12) and (4.13) are quite similar to equation (4.11), but they are different in that they are weighted by the value-added ratios given in equations (4.9) and (4.10). The reason for the value-added weighting is the assumption that North Carolina and Virginia share the amount of the commercial cigarettes smuggled into the northeastern and southeastern states. For a complete list of these states refer to Table 4.2. The reasoning for the population ratio weighted tax differentials is the same as that explained above for the state of Kentucky. The sign of the variable LDTAX for the three states of Kentucky, Virginia and North Carolina is predicted to be negative when included in regression equation (4.4) because the amount of cigarettes smuggled out of these states should vary in the same direction as the positive gap in taxes between the importing state and the low-tax exporting state. However, the tax differential is always a negative number because it is the lower-tax state's tax minus the higher-tax state's tax. Thus, the predicted sign of LDTAX is negative for the three long-distance commercial exporting states.

In order to control for the effects of both casual and commercial smuggling, the variables capturing the tax differential ($SDTIMP_t$, $SDTEXP_t$ and $LDTAX_t$) are included in regression equation (4.4). The modified regression equation is given by equation (4.14). The predicted signs of the smuggling variable coefficients (η_4, η_5 and η_6) are all negative. This modified regression equation now controls for interstate smuggling bias in the same way as Becker et al. In addition, post-information era structural breaks are specified for the smuggling variables in the same way that they were specified for the consumption and price variables in the model. The theory of rational addiction does not predict any structural breaks in the coefficients of the smuggling variables. However, since smuggling activity is related to cigarette sales in each state, the structural breaks for the smuggling variables are included for completeness.

$$C_t = \eta_0 + \eta_1 C_{t-1} + \gamma_1(INFO * C_{t-1}) + \eta_2 C_{t+1} + \gamma_2(INFO * C_{t+1})$$
$$+\eta_3 P_t + \gamma_3(INFO * P_t) + \eta_5 SDTIMP_t + \gamma_5(INFO * SDTIMP_t) + \eta_6 SDTEXP_t$$
$$+\gamma_6(INFO * SDTEXP_t) + \eta_7 LDTAX_t + \gamma_7(INFO * LDTAX_t) + \varepsilon_t \qquad (4.14)$$

In keeping with Becker et al., the only other variable that is included in the regression equation is annual state specific per capita disposable income INC_t along with its post-information era structural break specified in the same way that it was specified for the consumption and price variables in the model. Once again the theory does not predict a structural break in income, but nonetheless, one is specified for completeness. The complete regression equation is given by equation (4.15).

$$C_t = \eta_0 + \eta_1 C_{t-1} + \gamma_1(INFO * C_{t-1}) + \eta_2 C_{t+1} + \gamma_2(INFO * C_{t+1})$$
$$+\eta_3 P_t + \gamma_3(INFO * P_t) + \eta_4 INC_t + \gamma_4(INFO * INC_t) + \eta_5 SDTIMP_t$$
$$+\gamma_5(INFO * SDTIMP_t) + \eta_6 SDTEXP_t + \gamma_6(INFO * SDTEXP_t)$$
$$+\eta_7 LDTAX_t + \gamma_7(INFO * LDTAX_t) + \varepsilon_t \qquad (4.15)$$

A Description of the Data

The data set used in this model is comprised of state disaggregated annual time-series data for all the fifty states and the District of Columbia for a period of 1955-1994. This data set essentially extends the data set used by Becker et al. by a period of nine years. The data set is at the per capita level with a total of 1,989 potential observations. After eliminating observations due to missing sales and price data, the actual number of observations is reduced to 1,925. The details of the states missing sales and price data are contained in Table 4.3. Consumption C_t in equation (4.15) is measured by per capita tax-paid cigarette sales in packs.

These sales are reported for the fiscal year running from July 1 to June 30. The data are taken from The Tax Burden on Tobacco. The Tobacco Tax Council has obtained these data by means of a sample survey conducted in all states and the District of Columbia since 1954.

Because the consumption reported is for a fiscal year, it spans approximately half of each of two consecutive calendar years. It is for this reason that the price deflator that is used for calendar year t is a simple average of the 1982-1984 consumer price index for all commodities for the years t-1 and t. This series is taken from The Economic Report of the President,

Table 4.3. States with Missing Data

State	Years with Missing Data
Alaska	1955-1959
Hawaii	1955-1960
California	1955-1959
Colorado	1955-1964
Maryland	1955-1958
Missouri	1955
North Carolina	1955-1969
Oregon	1955-1966
Virginia	1955-1960

(1995). This price deflator is used to convert all nominal prices and taxes to their corresponding real values. Price P_t in equation (4.15) for year t is measured by the average of the year t-1 and t average retail prices reported by the Tobacco Tax Council. The state specific annual weighted average price per pack is calculated by the Tobacco Tax Council as follows. The average is taken over both the type of sale (i.e., single pack price, carton price and vending machine price) and over the different types of cigarettes sold (i.e., regular, king size, filter tip, etc.). This price is inclusive of state and federal excise taxes.

The state cigarette excise taxes that are used in the construction of the smuggling variables are weighted averages constructed from the state cigarette excise taxes reported by the Tobacco Tax Council for each fiscal year. The weights are the fractions of the fiscal year for which each rate has been in effect. The population figures for each state that are used in the construction of the smuggling variables are taken from the Current Population Reports for various years. Income INC_t in equation (4.15) for a state in year t is measured by the average of the year t-1 and t state specific per capita disposable income. These figures are taken from the Survey of Current Business (Various Years). Finally, it is appropriate to discuss the econometric procedures used to run the regressions.

Estimation Procedures and Instruments Used

Because the data set consists of state-specific time-series, a fixed effects model that employs state-specific and annual dummies is used. This is in keeping with the procedure used by Becker et al. who employed a similar data set. The annual dummies pick up the yearly effects of health information and the recent media coverage of the tobacco industry, while the state dummies compensate for the diversity in demographic composition, income and other state specific variables that may be correlated with cigarette consumption.

Another similarity in the estimation with Becker et al. arises from the fact that the variables C_{t-1} and C_{t+1} in equation (4.15) are endogenous. As Becker et al. point out the endogeniety becomes apparent when the dependence of C_{t-1} on e_t in the first order conditions given by equations (3.13) and (3.14) is explored. Furthermore, they reject the null hypothesis of consistent OLS estimates at the one percent level using a De-Min Wu F-test. Further arguments in support of the endogeneity of C_{t-1} and C_{t+1} come from Chaloupka. In keeping with Chaloupka, a perusal of the closed form solution to the difference equation given by equation (4.2) shows that consumption at any point in time depends on several future and past prices. However, the regression equation (4.15) does not contain any leads or lags of price.

A potential solution to the endogeneity problem will involve estimating C_{t-1} and C_{t+1} using various instrumental variables. Some of these instruments may be lagged and lead values of prices and taxes. In keeping with Becker et al., several different sets of instruments will be used. In general, two different sets of instruments are available. The former contains both lag and lead values of prices and taxes as instruments while the latter contains only the lag values of prices and taxes.

Becker et al. favor the sets of instruments that use both the lag and lead values of the price and tax variables. They are opposed to using instrument sets that omit future prices and taxes because they maintain that future prices and taxes are good indicators of future consumption. They state that cigarette tax hikes are publicized in advance thereby giving consumers a fair idea about future prices. They argue that to omit the one period lead values of prices and taxes from the set of instruments might lead to a loss of valuable information. Furthermore, they claim that the lagged values of prices and taxes are not good predictors of future prices. However, Becker et al. admit that if consumers have poor forecasts of future prices, then the forecast error in future price will create a downward bias in the coefficient of future consumption. Finally, they argue that another reason to use future prices and taxes as instruments is that models that use these instruments are much less sensitive to changes in the specification of the structural demand equation. Thus, regressions using both sets of instruments will be considered.

Another concern is the presence of Serial Correlation and Heteroscedasticity. Becker et al. computed a variance-covariance matrix that was adjusted for the effects of serial correlation. They claim that the corrected standard errors were not very different from the standard errors that were obtained without the correction. They also used weighted least squares to correct for the effects of any heteroscedasticity that may have been present. Once again, they report that their results do not change significantly. Since the data set that is used here is essentially an extension of the Becker et al. data the concerns regarding serial correlation and heteroscedasticity have already been addressed by the analysis performed by Becker et al. The chapter concludes with Table 4.4 which summarizes the expected signs of the estimated coefficients in the demand equation.

Table 4.4. Regression Coefficients and their Predicted Signs

Variables	Regression	Predicted Sign
C_{t-1}	η_1	Positive
C_{t+1}	η_2	Zero
P_t	η_3	Negative
INC_t	η_4	Indeterminate
$SDTIMP_t$	η_5	Negative
$SDTEXP_t$	η_6	Negative
$LDTAX_t$	η_7	Negative
$INFO*C_{t-1}$	γ_1	Negative
$INFO*C_{t+1}$	γ_2	Positive
$INFO*P_t$	γ_3	Positive
$INFO*INC_t$	γ_4	Indeterminate
$INFO*SDTIMP_t$	γ_5	Indeterminate
$INFO*SDTEXP_t$	γ_6	Indeterminate
$INFO*LDTAX_t$	γ_7	Indeterminate

CHAPTER 5.
EMPIRICAL RESULTS AND THEIR IMPLICATIONS

The purpose of this chapter is to report the empirical results based on the theory and methods developed in the previous chapters and to discuss the implications of these findings. The chapter begins with an outline of the choice of different sets of instruments used in the various regressions. Next, the results from the various regression runs will be presented. The implications of these results will be discussed. Thereafter, the regressions results from estimating the Becker et al. model using the updated dataset will be presented and compared to the empirical results of the model developed in this study. Finally, the chapter concludes with an overview of the simulations that were performed using the closed form solution to the difference equation developed in the theory chapter.

Choice of Instrumental Variables

The regression equation (4.15) that was developed in Chapter 4 contains two right hand side variables that are endogenous. This equation is reproduced here for convenience as equation (5.1).

$$\begin{aligned} C_t = {} & \eta_0 + \eta_1 C_{t-1} + \gamma_1(\text{INFO} * C_{t-1}) + \eta_2 C_{t+1} + \gamma_2(\text{INFO} * C_{t+1}) \\ & + \eta_3 P_t + \gamma_3(\text{INFO} * P_t) + \eta_4 \text{INC}_t + \gamma_4(\text{INFO} * \text{INC}_t) + \eta_5 \text{SDTIMP}_t \\ & + \gamma_5(\text{INFO} * \text{SDTIMP}_t) + \eta_6 \text{SDTEXP}_t + \gamma_6(\text{INFO} * \text{SDTEXP}_t) \\ & + \eta_7 \text{LDTAX}_t + \gamma_7(\text{INFO} * \text{LDTAX}_t) + \varepsilon_t \qquad (5.1) \end{aligned}$$

As Chapter 4 points out, past consumption C_{t-1} and future consumption C_{t+1} depend on several past and future prices which are absent from the regression equation. Thus, C_{t-1} and

C_{t+1} are not truly exogenous. When faced with the same problem, Becker et al. devise several different sets of instrumental variables to account for the endogeneity of past and future consumption. They use different combinations of lags and leads of cigarette prices and excise taxes along with the other explanatory variables in the model. This study uses a similar approach. The different combinations of lag and lead prices and taxes used by Becker et al. are replicated along with all the other explanatory variables. The details of the different sets of instrumental variables are contained in Tables 5.1 and 5.2. There are four different sets of instrumental variables labeled model (i) through (iv). In the context of these tables, X_{t-i} refers to the ith lag of the variable X, and X_{t+i} refers to the ith lead of the variable X. The variable T_t refers to annual state cigarette excise tax per pack. Table 5.1 contains both lead and lag values of the price and tax instruments used. Table 5.2 contains only those instrumental variable combinations that do not use any lead values of prices or taxes. In addition to the various leads and lags of prices and taxes, each set of instruments also contains all other explanatory variables in the model.

The estimation procedure used is two-stage least squares which is perhaps best explained using an example. Consider performing the two-stage least squares procedure using model (i) in Table 5.1. This involves regressing each endogenous variable C_{t-1} and C_{t+1} separately on all the truly exogenous variables in equation (5.1), i.e., P_t, (INFO*P_t), INC_t, (INFO*INC_t), $SDTIMP_t$, $SDTEXP_t$, $LDTAX_t$, (INFO*$SDTIMP_t$), (INFO*$SDTEXP_t$), (INFO*$LDTAX_t$) and the instruments P_{t-1} and P_{t+1}. The predicted values from each of these first stage regressions are stored. Next, a second OLS is run on equation (5.1). However, rather than using the actual values of C_{t-1} and C_{t+1} in the regression, their predicted values obtained from the first stage regressions are used. The estimates of the coefficients from this second stage are referred to as the two-stage least squares estimates. On the other hand, the OLS procedure estimates equation (5.1) using the actual values of C_{t-1} and C_{t+1} and all the other variables. These estimates are referred to as model (v).

Table 5.1. Sets of Lag and Lead Instruments for C_{t-1} and C_{t+1}

Model	Instruments Used
(i)	P_{t-1} and P_{t+1}
(ii)	P_{t-1}, P_{t+1} T_t and T_{t-1}
(iii)	P_{t-1}, P_{t+1} T_t, T_{t-1} and T_{t+1}
(iv)	P_{t-2}, P_{t-1}, P_{t+1} T_t, T_{t-1}, T_{t+1} and T_{t-2}

Table 5.2. Sets of Lag Instruments for C_{t-1} and C_{t+1}

Model	Instruments Used
(vi)	P_{t-1} and P_{t-2}
(vii)	P_{t-1}, T_t and T_{t-1}
(viii)	P_{t-2}, P_{t-1}, T_t, T_{t-1} and T_{t-2}

Summary of Regression Results

In keeping with Becker et al., equation (5.1) was estimated using ordinary least squares and the seven different sets of instruments that are outlined in Tables 5.1 and 5.2. The results are presented in Tables 5.3, 5.4, 5.5 and 5.6. The instrumental variables used in the regressions from Tables 5.3 and 5.4 contain both lag and lead values of prices and taxes. The next sub-section will report estimates of the rational addiction model with structural breaks using sets of instruments that contain lag and lead values of prices and taxes. Next, the economic implications of these results will be discussed. The following sub-section reports estimates of the rational addiction model with structural breaks using sets of instruments that contain only lag values of prices and taxes. The last sub-section will report estimates from a restricted rational addiction model with structural breaks. The restrictions are generated by imposing fixed values of the time preference parameter β.

Regressions that Use Both Lag and Lead Instruments

Table 5.3 presents the regression coefficients η_1 through η_7 and γ_1 through γ_7 of equation (5.1). The estimates in columns (i) through (iv) correspond to instrument sets (i) through (iv), respectively, as described in Table 5.1. Column (v) gives the ordinary least squares estimates of equation (5.1). The corresponding R^2 statistic and sample size N are also reported. The asymptotic two-tailed t-ratio accompanying each coefficient is reported beneath it in parentheses. Estimates of the state and time dummies for model (iv) are given in Appendix D. Table 5.3 presents the estimated slope coefficients in some detail. However, for the purposes of interpretation, it is beneficial to use these coefficients to obtain the pre-information and the post-information regression coefficients for each set of instruments. Table 5.4 presents one such description of the results contained in Table 5.3.

Table 5.4 reports the pre-information and post-information coefficients for equation (5.1) in accordance with the procedures outlined in Table 4.1. The pre-information coefficients in Table 5.4 are given by the η's from Table 5.3. The post-information coefficients reported in Table 5.4 are generated by the sum of the corresponding η's and γ's from Table 5.3. The R^2 statistic is also carried over from Table 5.3. In addition to this, Table 5.4 reports the estimates of the time-preference parameter β and its corresponding real interest rate r. β and r will be discussed in detail in a later section.

A systematic perusal of Table 5.4 allows one to grasp the implications of the econometric results for the theory. The left half of the table gives the estimates of the demand equation parameters in the pre-information years (pre-1979 coefficients), and the right half of the table gives the parameters of the demand equation pertinent to the post-information years

Table 5.3. Estimates of Cigarette Demand with Structural Breaks

Lags and Leads Included in Set of Instruments

(Asymptotic t-ratios are in parentheses)

Variables	Coefficients[a]	2SLS[b]				OLS[c]
		(i)	(ii)	(iii)	(iv)	(v)
C_{t-1}	η_1	0.557	0.445	0.509	0.562	0.489
		(7.438)	(6.411)	(7.845)	(9.696)	(32.380)
C_{t+1}	η_2	0.054	0.105	0.013	0.056	0.437
		(0.607)	(1.210)	(0.172)	(0.784)	(27.090)
P_t	η_3	-34.886	-39.473	-41.633	-34.290	-10.833
		(-6.752)	(-7.600)	(-7.833)	(-7.354)	(-3.849)
INC_t	η_4	0.184	0.223	0.227	0.180	0.061
		(4.467)	(5.328)	(5.197)	(4.631)	(2.241)
$SDTIMP_t$	η_5	-59.116	-59.513	-64.894	-58.706	-27.821
		(-5.826)	(-5.665)	(-6.105)	(-6.001)	(-4.132)
$SDTEXP_t$	η_6	-60.478	-65.938	-69.743	-59.726	-24.906
		(-8.503)	(-9.212)	(-9.654)	(-9.382)	(-6.902)
$LDTAX_t$	η_7	-8.773	-9.670	-10.597	-9.059	-1.226
		(-5.666)	(-6.163)	(-6.751)	(-6.289)	(-1.522)
$INFO*C_{t-1}$	γ_1	-0.246	-0.169	-0.248	-0.248	0.001
		(-2.862)	(-2.02)	(-3.193)	(-3.500)	(0.392)
$INFO*C_{t+1}$	γ_2	0.294	0.232	0.314	0.291	-0.008
		(3.360)	(2.694)	(3.938)	(4.012)	(-0.255)
$INFO*P_t$	γ_3	15.305	17.350	18.511	15.545	3.469
		(3.357)	(3.663)	(3.766)	(3.500)	(1.059)
$INFO*INC_t$	γ_4	-0.211	-0.258	-0.269	-0.205	-0.030
		(-5.577)	(-6.944)	(-6.992)	(-6.179)	(-1.633)
$INFO*SDTIMP_t$	γ_5	11.024	5.828	8.027	10.344	12.145
		(1.149)	(0.585)	(0.776)	(1.082)	(1.702)
$INFO*SDTEXP_t$	γ_6	14.518	16.384	18.338	13.872	-1.315
		(1.963)	(2.12)	(2.288)	(1.905)	(-0.241)
$INFO*LDTAX_t$	γ_7	-0.655	-0.717	-0.764	-0.920	-0.229
		(-0.855)	(-0.890)	(-0.908)	(-1.178)	(-0.383)
	R^2	0.970	0.967	0.964	0.971	0.982
	N	1925	1925	1925	1874	1925

[a] Intercepts for model (iv) are reported in Appendix D.

[b] Columns (i)-(iv) give 2SLS estimates with instruments described in Table 5.1

[c] Column (v) gives an OLS estimate.

Table 5.4 Pre and Post-Information Estimates of Cigarette Demand

Lags and Leads Included in Set of Instruments

(Asymptotic t-ratios are in parentheses)

RHS	PRE-1979 COEFFICIENTS						POST-1979 COEFFICIENTS					
Variables	Reg	2SLS[b]				OLS[c]	Reg	2SLS[b]				OLS[c]
	Coef[a]	(i)	(ii)	(iii)	(iv)	(v)	Coef	(i)	(ii)	(iii)	(iv)	(v)
C_{t-1}	η_1	0.557	0.445	0.509	0.562	0.489	$\eta_1+\gamma_1$	0.312	0.276	0.261	0.314	0.491
		(7.438)	(6.411)	(7.845)	(9.696)	(32.380)		(6.913)	(6.020)	(5.514)	(7.500)	(17.656)
C_{t+1}	η_2	0.054	0.105	0.013	0.056	0.437	$\eta_2+\gamma_2$	0.348	0.338	0.328	0.347	0.429
		(0.607)	(1.210)	(0.172)	(0.784)	(27.090)		(9.081)	(8.448)	(7.902)	(9.240)	(15.170)
P_t	η_3	-34.886	-39.473	-41.633	-34.290	-10.833	$\eta_3+\gamma_3$	-19.581	-22.123	-23.122	-18.745	-7.365
		(-6.752)	(-7.600)	(-7.833)	(-7.354)	(-3.849)		(-4.824)	(-5.287)	(-5.323)	(-4.827)	(-2.627)
INC_t	η_4	0.184	0.223	0.227	0.180	0.061	$\eta_4+\gamma_4$	-0.027	-0.035	-0.042	-0.025	0.031
		(4.467)	(5.328)	(5.197)	(4.631)	(2.241)		(-0.895)	(-1.105)	(-1.266)	(-0.820)	(1.369)
$SDTIMP_t$	η_5	-59.116	-59.513	-64.894	-58.706	-27.821	$\eta_5+\gamma_5$	-48.092	-53.685	-56.868	-48.362	-15.676
		(-5.826)	(-5.665)	(-6.105)	(-6.001)	(-4.132)		(-5.409)	(-5.885)	(-6.053)	(-5.732)	(-2.714)
$SDTEXP_t$	η_6	-60.478	-65.938	-69.743	-59.726	-24.906	$\eta_6+\gamma_6$	-45.960	-49.554	-51.405	-45.854	-26.221
		(-8.503)	(-9.212)	(-9.654)	(-9.382)	(-6.902)		(-5.008)	(-5.178)	(-5.163)	(-5.087)	(-3.868)
$LDTAX_t$	η_7	-8.773	-9.670	-10.597	-9.059	-1.226	$\eta_7+\gamma_7$	-9.428	-10.386	-11.361	-9.979	-1.455
		(-5.666)	(-6.163)	(-6.751)	(-6.289)	(-1.522)		(-5.101)	(-5.500)	(-5.949)	(-5.612)	(-1.340)
R^2		0.970	0.967	0.964	0.971	0.982		0.970	0.967	0.964	0.971	0.982
β		0.097	0.237	0.026	0.099	0.894		1.115	1.224	1.258	1.105	0.875
r		9.342	3.227	36.931	9.107	0.119		-0.103	-0.183	-0.205	-0.095	0.143

[a] Intercepts for model (iv) are reported in Appendix D.

[b] Columns (i)-(iv) give 2SLS estimates with instruments described in Table 5.1

[c] Column (v) gives an OLS estimate.

(post-1979 coefficients). Once again, the coefficients in any particular column correspond to the estimates obtained by using the set of instruments indicated by the column number.

In the pre-information years the estimates of the coefficient of past consumption (η_1) range from 0.445 to 0.557, and in the post-information years the estimates of the coefficient of past consumption ($\eta_1+\gamma_1$) range from 0.261 to 0.491. These estimates are all positive in sign and significant at the one percent level. Thus, the results show that past consumption is a positive and significant variable both in the pre-information and in the post-information years. These findings support the theoretical prediction of a positive coefficient on past consumption for an addictive good.

In the pre-information years the estimates of the coefficient of future consumption (η_2) range from 0.013 to 0.437. These estimates are also always positive in sign. In the pre-information years with the exception of the OLS estimate reported in column (v), all the coefficient estimates of future consumption are not significantly different from zero at the one percent level of significance. In other words, the results suggest that agents are myopic in the pre-information period. In the post-information years the estimates of the coefficient of future consumption ($\eta_2+\gamma_2$) range from 0.328 to 0.429. These estimates are all positive in sign and statistically significant at the one percent level. With the exception of the OLS estimates, the results show that future consumption becomes a significant variable in the post-information years, whereas it is not significant in the pre-information years. These results support the hypothesis maintained in this study that agents are myopic in the pre-information period due to a lack of information, but become rational after the release of addiction information.

The estimates of the coefficient of price are all negative and significant at the one percent level. They range from -34.886 to -10.833 in the pre-information period and from -23.122 to -7.365 in the post-information period. In general, they decrease in absolute value between the pre-information and the post-information period. These findings support the theoretical prediction of a negative coefficient on price in both periods. Furthermore, they support the prediction that the coefficient of price in the post-information period will be smaller in absolute value than its pre-information counterpart.

The estimates of the coefficient of income range from 0.061 to 0.227 in the pre-information period and are all significant at the one percent level, except for the OLS case which is significant at the five percent level. However, in the post-information period the estimates of the coefficient of income, with the exception of the OLS estimate, are negative in sign. In this period they are also not significantly different from zero at the five percent level. Thus, in general, with the exception of the OLS case, the coefficient of income appears to switch signs and lose significance in the post-information period. The theory does not make any predictions about the magnitude or the significance of the coefficient of income.

The coefficients of the three smuggling indices are all negative in sign in both periods. With the exception of a couple of OLS estimates, they are also always significant at the one percent level. The structural breaks in the estimates of the coefficients (γ_5 and γ_6) of the casual smuggling indices $SDTIMP_t$ and $LDTAX_t$ reported in Table 5.3 are not significantly different from zero at the five percent significance level. However, the estimates of the coefficients of the commercial smuggling index $SDTEXP_t$ do exhibit a significant structural break. This results in an increase in absolute value of the coefficient of the commercial smuggling index $SDTEXP_t$ between the pre-information and the post-information period. Because these indices are not considered in the theoretical model, there are no a priori expectations about the magnitudes or signs of the coefficients of the structural breaks for these variables.

In general, the γ coefficients are significant as a group. The null hypothesis of all the γ coefficients being zero is rejected at the one percent level of significance for models (i) through (iv). The calculated F-statistics for these models (i) through (iv) are: 5.59, 7.31, 8.31 and 7.03 respectively. The large F-statistics merely reconfirm the significance of the presence of structural breaks indicated by the large t-statistics for individual γ coefficients.

Economic Implications of the Regression Results

The regression results from Table 5.4 hold several implications for the theory. The coefficient of past consumption always enters the regression equation with a positive sign. This is in keeping with the notion that a higher level of past consumption will spur an increase in current consumption for an addictive good. This coefficient is positive and significant in both the pre-information and the post-information periods. Thus, the regressions support the theoretical notion of the addictiveness of nicotine regardless of the availability of addiction information. These results provide empirical evidence that refutes the tobacco industry's claims that cigarettes are not addictive.

The coefficient of future consumption is not significantly different from zero in the pre-information period. However, in the post-information period it is positive and significant at the one percent level. This lends credibility to the hypothesis that once consumers are explicitly informed of the future consequences of consuming an addictive good, their current choices do reflect a consideration of the impact of those choices on their future satisfaction. In other words, in the absence of addiction information, consumers tend to make myopic consumption choices, but once informed of the addictive nature of the good, they make rational choices that display an explicit consideration of the future impact of current consumption.

A perusal of the estimates of the coefficient of price suggest that an increase in the price per pack of cigarettes would lead to a decline in the per capita consumption of cigarettes both in the pre-information and in the post-information period. However, in the post-information period the decline in the absolute value of the price coefficient estimates for all sets of instruments suggests that after the addictive properties of nicotine are disclosed, a price cut loses some of its sales generating ability. In other words, cigarette consumers who are not aware of the addictive properties of nicotine are likely to increase consumption by a greater amount in response to a price cut than if they were aware of the addictive aspects of nicotine. A given rise in prices due to an increase in cigarette taxes would not generate as large a decrease in consumption in the post-information period as it would in the pre-information period. Thus, the results seem to imply that the efficacy of cigarette taxes as a deterrent is mitigated by the presence of addiction information.

The two-stage least squares estimates of the coefficient on income suggest that cigarettes switch from normal to slightly inferior or income neutral good after the disclosure of the addictive properties of nicotine. In other words, a rise in income for a consumer in the pre-information period will be accompanied by an increase in per capita cigarette consumption, whereas a rise in income for a consumer in the post-information period will be accompanied by a slight decrease in per capita cigarette consumption.

The estimates of the coefficients of all the smuggling indices are negative and significant in both the pre-information and the post-information time periods. These findings suggest that both casual and commercial smuggling were prevalent in both time periods. The only estimates that display a structural break between the two periods are the estimates of the variable SDTEXP.

The empirical results support the theory quite strongly. The two-stage least squares results are not sensitive to the choice of instruments specified in Table 5.1. The hypothesized shift from a myopic to a rational pattern of consumption is observed. In the post-information period the magnitude of the impact of past consumption on current consumption is predicted to decline and this is supported by the negative sign on the estimates of γ_1 for all sets of instruments Table 5.3. Furthermore, the prediction of a drop in the power of price to stimulate consumption in the post-information period is supported by a positive sign on the estimates of γ_3 for all sets of instruments in Table 5.3.

Regressions that Use Only Lag Instruments

In keeping with Becker et al., a second series of regressions was run using instrumental variables that excluded any lead values of prices and taxes. The instrument sets are designated (vi) through (viii) and are described in detail in Table 5.2. The results from these regressions are presented in Table 5.5. Next, these regression results are rephrased to state the corresponding pre-information and post-information coefficients. The pre-information and post-information coefficients are represented in Table 5.6. The construction of Table 5.6 from Table 5.5 is completely analogous to that of Table 5.4 from Table 5.3.

The results from this second set of regressions are less favorable. The pre-information estimates are the most troublesome. The estimates of the coefficient of past consumption are negative but insignificant; the price coefficient estimates are positive and significant in two out of three regressions. In addition, the estimates of the coefficients of each of the casual smuggling indices ($SDTIMP_t$ and $SDTEXP_t$) are negative in only one out of three regressions while the estimated coefficient of the commercial smuggling index ($LDTAX_t$) is always positive. However, these regressions do offer some support for the model in that the pre-information period estimates of the coefficient of future consumption are positive and significant in all three regressions.

The post-information coefficients do offer limited support for the theory. While the estimates of the coefficients on both past and future consumption are always positive and significant, the estimates of price are negative and significant in only two out of three regressions. The estimates of the coefficients of each of the casual smuggling indices still have the wrong signs in the majority of the regressions.

Becker et al. had similar problems with the second set of regression instruments as well. However, they argue that any set of instruments that attempts to predict future consumption without a consideration of future prices or taxes is inherently flawed, and as such, not much weight should be placed on the results of these regressions. This is because

Table 5.5. Estimates of Cigarette Demand with Structural Breaks

Only Lags are Included in Set of Instruments

(Asymptotic t-ratios are in parentheses)

Variables	Coefficients	2SLS [a] (vi)	(vii)	(viii)
C_{t-1}	η_1	-1.157	-0.011	-0.140
		(-0.809)	(-0.066)	(-0.854)
C_{t+1}	η_2	2.841	0.953	1.245
		(1.284)	(3.359)	(4.660)
P_t	η_3	46.090	-9.547	2.357
		(0.758)	(-0.885)	(0.243)
INC_t	η_4	-0.031	0.115	0.073
		(-0.175)	(2.168)	(1.394)
$SDTIMP_t$	η_5	22.751	1.333	5.142
		(0.934)	(0.348)	(1.467)
$SDTEXP_t$	η_6	118.690	-3.990	18.499
		(0.845)	(-0.196)	(0.912)
$LDTAX_t$	η_7	78.471	-17.738	2.404
		(0.746)	(-1.051)	(0.156)
$INFO*C_{t-1}$	γ_1	2.060	0.504	0.724
		(1.107)	(2.193)	(3.239)
$INFO*C_{t+1}$	γ_2	-2.141	-0.497	-0.741
		(-1.099)	(-2.008)	(-3.135)
$INFO*P_t$	γ_3	-27.376	1.990	-3.854
		(-0.795)	(0.298)	(-0.566)
$INFO*INC_t$	γ_4	0.263	-0.068	0.017
		(0.765)	(-0.958)	(0.268)
$INFO*SDTIMP_t$	γ_5	2.443	-0.128	0.550
		(0.713)	(-0.162)	(0.552)
$INFO*SDTEXP_t$	γ_6	-51.793	-7.615	-14.433
		(-0.875)	(-0.730)	(-1.135)
$INFO*LDTAX_t$	γ_7	-54.179	-6.749	-16.462
		(-0.976)	(-0.646)	(-1.502)
	R^2	0.759	0.970	0.957
	N	1874	1925	1874

[a] Columns (vi)-(viii) give 2SLS estimates with instruments described in Table 5.2

Table 5.6 Pre and Post-Information Estimates of Cigarette Demand

Only Lags are Included in Set of Instruments

(Asymptotic t-ratios are in parentheses)

RHS Variables	PRE-1979 COEFFICIENTS				POST-1979 COEFFICIENTS			
	Reg Coef	2SLS [a]			Reg Coef	2SLS [a]		
		(vi)	(vii)	(viii)		(vi)	(vii)	(viii)
C_{t-1}	η_1	-1.157	-0.011	-0.140	$\eta_1+\gamma_1$	0.903	0.494	0.584
		(-0.809)	(-0.066)	(-0.854)		(2.013)	(5.999)	(7.575)
C_{t+1}	η_2	2.841	0.953	1.245	$\eta_2+\gamma_2$	0.700	0.457	0.504
		(1.284)	(3.359)	(4.660)		(2.433)	(8.473)	(8.905)
P_t	η_3	46.090	-9.547	2.357	$\eta_3+\gamma_3$	18.714	-7.557	-1.497
		(0.758)	(-0.885)	(0.243)		(0.634)	(-1.231)	(-0.251)
INC_t	η_4	-0.031	0.115	0.073	$\eta_4+\gamma_4$	0.232	0.047	0.090
		(-0.175)	(2.168)	(1.394)		(1.092)	(1.171)	(2.028)
$SDTIMP_t$	η_5	118.690	-3.990	18.499	$\eta_5+\gamma_5$	66.897	-11.605	4.066
		(0.845)	(-0.196)	(0.912)		(0.755)	(-0.734)	(0.267)
$SDTEXP_t$	η_6	78.471	-17.738	2.404	$\eta_6+\gamma_6$	24.292	-24.487	-14.058
		(0.746)	(-1.051)	(0.156)		(0.418)	(-2.015)	(-1.091)
$LDTAX_t$	η_7	22.751	1.333	5.142	$\eta_7+\gamma_7$	25.194	1.205	5.693
		(0.934)	(0.348)	(1.467)		(0.930)	(0.292)	(1.428)
R^2		0.759	0.970	0.957		0.759	0.970	0.957
β		-2.456	-89.631	-8.867		0.775	0.925	0.863
r		-1.407	-1.011	-1.113		0.291	0.081	0.158

[a] Columns (vi)-(viii) give 2SLS estimates with instruments described in Table 5.2

they are based on incomplete sets of instruments. The next section will discuss the results from the estimation of a restricted rational addiction model with structural breaks.

Estimates of the Restricted Rational Addiction Model with Structural Breaks

The time preference parameter β, as stated in Chapter 3 in equation (3.10), is the rate at which the agent discounts the contribution of a future period's utility to the sum of the present discounted value of the utility stream. β can be recovered from the coefficients of the regression equation. This is demonstrated in Appendix C. In any particular regression equation it is given by the ratio of the coefficient of future consumption C_{t+1} to the coefficient of past consumption C_{t-1}.

Tables 5.4 and 5.6 also report the time preference parameter β and its associated interest rate r. In Table 5.4 (the regressions with both lag and lead instruments) the two-stage least squares estimates of the pre-information β range from 0.026 to 0.099 and the corresponding interest rates range from 3693 to 910.7 percent. These values of β are implausibly low, while the accompanying interest rates are implausibly high. However, the post-information estimates of β are implausibly high. They range from 1.105 to 1.258, and the corresponding interest rates range from -9.5 percent to -20.5 percent. In Table 5.6 (the regressions with only lag instruments) the two-stage least squares estimates of the pre-information β range from -89.631 to -2.456 and the corresponding interest rates range from -101 percent to -140.7 percent. The post-information estimates of β range from 0.775 to 0.925 and the corresponding interest rates range from 29 percent to 8.1 percent. Apart from these last estimates, the estimates of β, in general, are troubling because they either imply interest rates that are too high or they imply negative interest rates. The interest rates obtained by these regression estimates cast suspicion on the robustness of the model. Becker et al. admit to having a model which does not produce very plausible estimates of the time preference parameter β and, consequently, of the real interest rate r.

Becker et al. report that the values of the time preference parameter β implied by their regression estimates are implausibly low. In order to investigate the robustness of their model, they redo the estimation with values of β fixed at plausible levels. Since the results from Table 5.4 show that the rational addiction model with structural breaks suffers from the problem of high interest rates in the pre-information period and negative interest rates in the post-information period, the model was re-estimated using values of β fixed at more plausible values. Only model (iv) was re-estimated. The results from these regressions are reported in Table 5.7.

The basic findings that are reported in Table 5.4 remain unaltered by the imposition of different values of β ranging from 0.75 to 0.95. These values of β correspond to interest rates of 0.33 and 0.05, respectively. As the results in Table 5.7 show, there is still a shift from a myopic to a rational pattern of consumption after the release of addiction information. The influence of past consumption on current consumption gets stronger after the release of addiction information. The influence of price on current consumption declines in the post-information period compared to its influence on consumption in the pre-information period. The smuggling indices retain their negative signs as predicted by the theory. In essence, the imposition of reasonable discount factors does little to undermine the empirical support for the rational addiction model with structural breaks.

Empirical Results from the Becker et al. Rational Addiction Model

This section presents the results from estimating a rational addiction demand equation without structural breaks over the time period 1955-1994. This model is just the Becker et al. model estimated using the updated data set developed for this study. The estimates from the

Table 5.7 Pre and Post-Information Estimates of Cigarette Demand,

with exogenously imposed values of β

Lags and Leads Included in Set of Instruments [a]

(Asymptotic t-ratios are in parentheses)

		PRE-1979 COEFFICIENTS						POST-1979 COEFFICIENTS						
RHS	Reg	r=0.43	r=0.33	r=0.25	r=0.18	r=0.11	r=0.05	Reg	r=0.43	r=0.33	r=0.25	r=0.18	r=0.11	r=0.05
Variables	Coeff	β=0.70	β=0.75	β=0.80	β=0.85	β=0.90	β=0.95	Coeff	β=0.70	β=0.75	β=0.80	β=0.85	β=0.90	β=0.95
C_{t-1}	η_1	0.569	0.567	0.566	0.566	0.565	0.564	$\eta_1+\gamma_1$	0.391	0.380	0.369	0.359	0.350	0.340
		(9.893)	(9.88)	(9.863)	(9.842)	(9.819)	(9.794)		(18.022)	(18.068)	(18.097)	(18.111)	(18.112)	(18.103)
C_{t+1}	η_2	0.083	0.078	0.074	0.070	0.066	0.062	$\eta_2+\gamma_2$	0.391	0.380	0.369	0.359	0.350	0.340
		(0.820)	(0.835)	(0.842)	(0.844)	(0.841)	(0.832)		(18.022)	(18.068)	(18.097)	(18.111)	(18.112)	(18.103)
P_t	η_3	-33.763	-33.753	-33.772	-33.816	-33.880	-33.961	$\eta_3+\gamma_3$	-18.995	-18.899	-18.827	-18.776	-18.743	-18.725
		(-7.304)	(-7.31)	(-7.319)	(-7.331)	(-7.345)	(-7.359)		(-4.931)	(-4.907)	(-4.887)	(-4.872)	(-4.859)	(-4.850)
INC_t	η_4	0.171	0.172	0.173	0.174	0.175	0.176	$\eta_4+\gamma_4$	-0.032	-0.031	-0.030	-0.029	-0.028	-0.027
		(4.455)	(4.482)	(4.511)	(4.541)	(4.571)	(4.601)		(-1.061)	(-1.021)	(-0.986)	(-0.953)	(-0.923)	(-0.901)
$SDTIMP_t$	η_5	-58.899	-58.747	-58.644	-58.581	-58.554	-58.556	$\eta_5+\gamma_5$	-48.401	-48.259	-48.169	-48.123	-48.115	-48.138
		(-6.065)	(-6.052)	(-6.042)	(-6.033)	(-6.026)	(-6.02)		(-5.778)	(-5.765)	(-5.755)	(-5.750)	(-5.743)	(-5.740)
$SDTEXP_t$	η_6	-58.856	-58.855	-58.897	-58.974	-59.080	-59.211	$\eta_6+\gamma_6$	-46.155	-46.004	-45.896	-45.824	-45.783	-45.769
		(-9.332)	(-9.344)	(-9.359)	(-9.376)	(-9.394)	(-9.413)		(-5.160)	(-5.145)	(-5.133)	(-5.122)	(-5.114)	(-5.106)
$LDTAX_t$	η_7	-8.972	-8.955	-8.948	-8.951	-8.961	-8.978	$\eta_7+\gamma_7$	-9.814	-9.804	-9.805	-9.816	-9.836	-9.863
		(-6.276)	(-6.27)	(-6.269)	(-6.271)	(-6.277)	(-6.286)		(-5.565)	(-5.565)	(-5.570)	(-5.580)	(-5.588)	(-5.600)
R^2		0.971	0.971	0.971	0.971	0.971	0.971		0.971	0.971	0.971	0.971	0.971	0.971

[a] These Regressions were run using the set of instruments from model (iv) described in Table 5.1

regressions run on this model using the instrumental variables described in Tables 5.1 and 5.2 are reported in Tables 5.8 and 5.9, respectively. In keeping with the empirical findings in Becker et al., the regressions that use both lag and lead instruments (columns (i) through (iv) in Table 5.8) provide more support for the rational addiction model than the regressions that exclude future prices and taxes as instruments (columns (vi) through (viii) in Table 5.9).

The regressions labeled (i) through (iv) in Table 5.8 support the hypotheses that cigarette consumers are rational by the presence of positive estimates of the coefficient of future consumption. Furthermore, the positive estimates of the coefficient of future consumption provide support for the hypothesis that cigarettes are an addictive good. The negative estimates on the coefficient of price also support the theoretical predictions about the impact of price on current consumption. However, the coefficient of income is negative in two out of four regressions, whereas for the empirical results of Becker et al. which employs data from 1955-1985, the estimates of the coefficients of income are positive for all sets of instruments. The coefficients of the smuggling indices have the predicted negative signs.

One of the problems with the rational addiction model proposed by Becker et al is that the estimates of β inferred from the two-stage least squares estimates in Table 5.8 are implausibly low. They range from 0.34 to 0.62. In turn, these low values of β imply implausibly high values of the interest rate ranging from about sixty percent to one hundred and ninety-eight percent.

The regressions labeled (vi) through (viii) in Table 5.9 are also problematic for the Becker et al. rational addiction model. As is the case with the empirical model used in this study, some estimates of the coefficient of past consumption are negative, and one estimate of the coefficient of future consumption is insignificant at the five percent level. In two out of the three regressions, price has a negative coefficient. As Becker et al. point out, these aberrations are probably attributable to the use of an incomplete set of instrumental variables.

Table 5.8 Rational Addiction Model without Structural Breaks

Lags and Leads Included in Set of Instruments

(Asymptotic t-ratios are in parentheses)

RHS	2SLS				OLS
Variables	(i)	(ii)	(iii)	(iv)	(v)
C_{t-1}	0.517	0.396	0.457	0.513	0.489
	(9.041)	(7.685)	(9.881)	(12.470)	(36.760)
C_{t+1}	0.173	0.247	0.162	0.188	0.441
	(2.729)	(4.001)	(3.104)	(3.932)	(31.160)
P_t	-29.279	-33.265	-35.212	-27.795	-9.558
	(-7.489)	(-8.379)	(-8.742)	(-7.946)	(-4.281)
INC_t	-0.002	0.010	-0.003	0.000	0.038
	(-0.084)	(0.355)	(-0.121)	(-0.004)	(1.799)
$SDTIMP_t$	-47.213	-49.277	-53.466	-46.458	-20.382
	(-6.700)	(-6.752)	(-7.281)	(-6.946)	(-4.128)
$SDTEXP_t$	-55.012	-59.033	-62.813	-53.765	-25.633
	(-9.321)	(-9.744)	(-10.360)	(-9.962)	(-7.321)
$LDTAX_t$	-6.748	-7.006	-7.926	-6.857	-1.326
	(-5.591)	(-5.619)	(-6.45)	(-5.986)	(-1.743)
R^2	0.974	0.972	0.970	0.975	0.982
β	0.335	0.624	0.354	0.366	0.902
r	1.988	0.603	1.821	1.723	0.109
N	1925	1925	1925	1874	1925

Table 5.9 Rational Addiction Model without Structural Breaks

Only Lags are Included in Set of Instruments

(Asymptotic t-ratios are in parentheses)

RHS Variables	2SLS (vi)	(vii)	(viii)
C_{t-1}	-0.872	0.095	0.060
	(-0.792)	(1.087)	(0.676)
C_{t+1}	2.441	0.861	0.988
	(1.432)	(5.444)	(6.836)
P_t	41.854	-7.561	0.013
	(0.841)	(-1.040)	(0.002)
INC_t	0.378	0.105	0.134
	(1.280)	(2.925)	(3.549)
$SDTIMP_t$	84.651	-7.359	3.446
	(0.876)	(-0.597)	(0.303)
$SDTEXP_t$	73.604	-16.776	-4.425
	(0.798)	(-1.433)	(-0.428)
$LDTAX_t$	20.686	1.795	3.542
	(1.021)	(0.739)	(1.622)
R^2	0.780	0.972	0.967
β	-2.799	9.063	16.467
r	-1.357	-0.891	-0.940
N	1874	1925	1874

The next section compares and contrasts the empirical results of this study to those obtained from fitting the Becker et al. model to the updated data.

Contributions of the Rational Addiction Model with Structural Breaks

Although the Becker et al. model does not specifically account for the impact of addiction information on cigarette consumption, the empirical results from their model do have some commonalties with the empirical results of the model developed in this study which incorporates structural breaks. For the sake of brevity, comparisons and contrasts will only be made across the regressions that use future prices and taxes as instruments. In other words, the results from Table 5.4 will be compared to those in Table 5.8.

In general, both sets of results show that the two models agree on the signs of all the explanatory variables except for income. However, for each explanatory variable in the current study, there is a pre-information and a post-information coefficient. With the exception of income, the signs of all these variables in both the pre-information and the post-information period agree with the signs of the corresponding variables in the Becker et al. results. A comparison of the magnitudes of the coefficients on the price, income and consumption variables reveals an interesting fact. The estimate of each of the aforementioned coefficients from the Becker et al. model is bounded by the corresponding pre-information and post-information in the current model. For example, in Table 5.8 the regression (i) estimate of the coefficient on past consumption in the Becker et al. model is 0.517. This figure is bounded by 0.557 and 0.312, the corresponding estimates of the coefficient of past consumption from regression (i) in Table 5.4. This suggests that addiction information does have an explicit role to play in the demand equation.

The Becker et al. model is generally on the right track, but a model that accounts for the dissemination of addiction information provides more accurate estimates of the coefficients of the explanatory variables in the demand equation. This difference is most apparent in the case of the coefficient on future consumption. The Becker et al. model predicts that agents account for the future impact of addiction information even without the knowledge that a good is addictive. For example, in Table 5.8 regression (iv) has an estimate of 0.188 for the coefficient of future consumption which is significant at the one percent level. However, the rational addiction model with structural breaks demonstrates the following. When addiction information is explicitly included in the demand equation, then in fact, agents who do not know that cigarettes are addictive do not consider the future impact of current consumption. For example, in Table 5.4 regression (iv) has an estimate of 0.056 for the pre-information coefficient of past consumption which is not significantly different from zero at the five percent level. The structural break model hypothesizes that agents only consider the future impact of current consumption after they are made aware of the addictive properties of nicotine. For example, the estimate of the post-information coefficient on future consumption from regression (iv) in Table 5.4 is 0.347, and it is significant at the one percent level.

Simulations

The theoretical solution to the difference equation from Chapter 2 is used to simulate cigarette consumption from 1963 to 1987 given the assumption that addiction information would have been released in 1962 by the cigarette firms. These simulations are described in detail in Appendix E. The general findings are that for the vast majority of states, the simulated annual per capita consumption is less than the per capita consumption that was actually observed for these states.

CHAPTER 6.
SUMMARY AND CONCLUSIONS

A Précis of the Research Effort

Cigarette consumption has been an oft analyzed topic. The earliest studies in the 1950s modeled the demand for cigarettes as a non-addictive good. In general, the literature in this period treated the quantity of cigarettes demanded as a function of prices, income, advertising and taxes. The temporal dimension of current consumption was not considered.

In the mid 1960s and the early 1970s the first health warnings regarding cigarette consumption were issued by the Surgeon General. Furthermore, during this period, legislation was passed regarding cigarette labeling and advertising. These events prompted a renewed interest in the analysis of cigarette demand. Economists modified the previous non-addictive models to include annual dummies to pick up the effects of the health warnings and legislation. In addition to the health warnings, the Surgeon General informed the American public of the addictive nature of nicotine in 1979.

Once again, cigarette demand was analyzed with renewed vigor. This time, the studies attempted to incorporate the fact that the consumption of an addictive good had temporal consequences. In particular, current consumption was modeled as a function of past consumption in addition to other economic variables such as prices, personal income, taxes and advertising. These myopic models varied in their degree of sophistication. The simpler models maintained that current cigarette consumption depended on past consumption without providing a microeconomic foundation for their claim. Other myopic models provided a consistent utility maximization approach to the proposition that past consumption and the aforementioned economic variables influenced current consumption. The myopic theory of addiction was supported by empirical evidence. In addition to finding significant effects of cigarette prices, income, taxes and advertising, past consumption was also found to be a positive and significant determinant of current consumption. Thus, cigarette consumers were modeled as myopic or short-sighted individuals who did not consider the future consequences of their actions. The prevailing intuition of the myopic school was that since cigarettes were an addictive good, the quantity demanded would not respond much to changes in economic variables.

Becker and Murphy challenge the above logic. They maintain that economic agents are rational and do consider the future effects of their actions. Consequently, these agents do consider the future consequences of consuming an addictive good. Becker and Murphy incorporated the psychological aspects of tolerance, withdrawal and reinforcement into their optimal control theory of rational addiction. Their model implies that current consumption is not only influenced by past consumption but also by a consideration of the impact of current consumption on future utility. The rational addiction model also implies that economic variables such as prices and income could play a larger role in determining consumption than previously thought. In addition, the Becker and Murphy model relates the consumption of addictive goods to stressful life events and allows for the possibility of quitting cold turkey. Finally, this model allows for the possibility of a myopic consumer as a special case of the rational addiction model.

It is the ability of the rational addiction model to nest the myopic model within itself that permits the testing of the alternative hypotheses of myopia and rationality. The empirical evidence in favor of the rational addiction model is quite strong. The earliest empirical study to test the model was conducted by Becker et al. using state disaggregated U.S. annual time-series data. They find strong support for the rational addiction model. Their results suggest that both past and future consumption are appropriate determinants of current consumption. Their estimates of long-run price elasticities suggest that cigarette demand is more responsive to changes in price than previously thought. Chaloupka also finds additional empirical support for the rational addiction model using a panel data set that spans four years and twenty-eight thousand individuals. Chaloupka's model is a generalized version of the Becker et al. empirical model. In fact, the Becker et al. model is a special case of Chaloupka's model that occurs when the depreciation rate on the addictive stock is one hundred percent. Chaloupka finds that past and future prices and consumption are significant determinants of current consumption. In addition, he also obtains estimates of long-run elasticties which suggest that cigarette demand is quite responsive to changes in price. The findings of these studies present a problem for theorists from the myopic school because the myopic model does not predict that agents consider the future consequences of their current choices concerning addictive goods. The rational addiction model has emerged as the most widely accepted theory at the current time because it retains the ability to explain myopic behavior as a special case and is supported by strong empirical evidence.

An implicit assumption in the rational addiction model is that cigarette consumers are aware of the addictive nature of cigarettes. Although cigarette manufacturers were aware of the addictive properties of nicotine as early as 1962, the information did not become available to the general public until 1979 when it was disclosed by the Surgeon General. This set of events presents an opportunity to test the impact of addiction information on the demand for an addictive good. This study posits that the release of addiction information in 1979 served to make consumers aware of the implications of current consumption levels for future choices. Prior to 1979 in the absence of addiction information about a good, consumers had to rely on their past consumption experience of the addictive good. They adjusted their current consumption levels to maximize current utility while compensating for the effects of tolerance, reinforcement and withdrawal due to past consumption. However, consumers did not account explicitly for the effects of present consumption on future utility until they were informed about the addictive nature of the good in 1979. Once they were told about the addictive properties of the good, agents did consider the implications of current consumption for future utility. In other words, this study posits that a structural break should be observed in the demand for cigarettes in 1979. That is, in the absence of addiction information, the demand for an addictive good will be myopic and that after the release of addiction information in 1979 the demand for the addictive good will be rational.

The model constructed in this paper empirically modifies the rational addiction model to allow for the possibility of structural changes in the demand function which may have occurred beginning in 1979 due to the release of addiction information. It reconciles the competing models of myopia and rationality by accounting for the availability of addiction information to consumers. In addition to this, the theoretical model generalizes the rational addiction model to include non-addictive goods. This innovation nests the demand for both addictive and non-addictive goods as sub cases of a single demand equation. The subsequent rational addiction demand equation that is derived from this model retains the ability to distinguish between rational and myopic behavior. This model provides testable implications concerning the addictive nature of a good. It predicts that due to the addictive nature of cigarettes, past consumption will influence the level of current consumption regardless of the availability of addiction information. It also provides testable implications about myopic versus rational consumption patterns. Specifically, the theoretical model predicts that the impacts of past consumption and price on current consumption will decline after the release of addiction information. It also predicts that future consumption will become a significant determinant in the post-information rational demand equation.

The model was tested using U.S. annual state disaggregated time-series data from 1955-1994. The data set is essentially an updated version of that used by Becker et al.. The empirical estimation of the model accounts for the effects of casual and commercial smuggling due to diverse state cigarette excise tax rates. This is done by including indices that capture the incentives to smuggle cigarettes into and out of each state.

Several different regressions were run. They can be broadly classified into four sets. The first set of regressions estimates the rational addiction model with structural breaks using sets of instruments that contain both lag and lead values of cigarette prices and taxes. The second set repeats the estimation using sets of instruments that contain only lag values of cigarette prices and taxes. A third set of regressions using different reasonable fixed values of the time preference parameter is estimated because the estimates obtained from the first two sets of regressions yield implausible estimates of the time preference parameter. The fourth set of regressions estimates a rational addiction model without any structural breaks over the entire sample. This is essentially an updated version of the Becker et al. regressions.

The results from the empirical analysis support the theory quite strongly. There is a significant structural break in the coefficients of past consumption, future consumption and price which occurs in the year that information regarding the addictive aspects of cigarettes was released by the Surgeon General. The data are consistent with a myopic model in the pre-information period and a forward looking rational model in the post-information period. The results suggest that agents who are not explicitly informed of the future consequences of cigarette smoking do not consider the impact of current choices on their future well being. However, agents that are explicitly informed about the future implications of consuming an addictive good do consider the impact of current consumption on future choices when determining the amount of current consumption. In addition to the switch from a myopic to a rational pattern of consumption, the results also support theoretical predictions of the direction and magnitude of the structural breaks in the coefficients of the key variables. The data support the notion that in the absence of addiction information past consumption and price will have a larger impact on current consumption than in the presence of this information. These findings concur with the logic that when consumers know about the future impact of current consumption they modify their current consumption levels to ensure that they maximize their well being not only in the current time period but also in the future.

The data suggest that this modified behavior mitigates the effects of past consumption and prices on current consumption levels. The implication for using cigarette taxes as a policy tool is that cigarette consumption by consumers who are aware of the addictive nature of nicotine will respond less to a tax hike than the consumption levels of those consumers who are unaware of the addictive properties of nicotine. The model is robust to exogenously imposed time preference rates. The results are not sensitive to choices of the set of instruments given that future values of prices and taxes are used to predict future consumption.

Limitations and Directions for Future Research

Although this study does provide several fascinating insights into the impact of addiction information on the consumption of an addictive good, it does suffer from some limitations. The model presented here does not examine the determinants of the start and quit rates of cigarette smokers. Clearly, the revelation of addiction information will have some bearing on these rates and on the number of packs consumed by each smoker. The complete impact of addiction information on cigarette consumption will not be known until its effect on agents' decisions to smoke and to quit smoking is known. This provides an avenue for future research. A rational addiction model with structural breaks can be used to analyze the probabilities of starting and quitting smoking. In particular the decision of teenagers to start smoking can be examined based upon their knowledge of the addictive properties of nicotine. However, this type of analysis would require a detailed panel data set. This is another limitation of the current study. The data cannot be disaggregated beyond the state level. This precludes the ability of the study to track the change in cigarette consumption by specific individuals prior to and after the release of addiction information. However, the aggregate nature of the data does provide an overview of the impact of cigarette addiction information on the entire U.S. on a state by state basis.

The current effort develops a solution to the demand equation which appears to point out a restrictive assumption employed by Becker et al. and Chaloupka in the construction of their solutions to the same equation. This finding presents the possibility of updating the numerical estimates of their price-elasticities using the solution developed in this study.

The current study models the demand for cigarettes without considering the impact of substitutes and complements. For example, it does not examine the impact of alcohol consumption on cigarette demand. Another direction for future research is that the current model can be extended to multiple addictive goods. The interaction between the demands for complementary and competing addictive goods can be analyzed. Furthermore, it would be interesting to examine the impact of addiction information regarding one good on the demand for a substitute or complement. The model proposed here is a simple demand equation. A possible extension is to construct a larger system of demand equations which models the demands for multiple groups of addictive and non-addictive goods.

The current study explicitly introduces the depreciation rate as a factor in the addiction process. In this model the depreciation rate of the addictive stock is assumed to be a biologically determined constant. The tobacco industry has been accused of manipulating nicotine levels. Fluctuating nicotine levels in cigarettes may in fact make the depreciation rate a variable. Further research incorporating uncertainty with respect to the depreciation rate is warranted.

The availability of low-tar and light varieties of cigarettes offer consumers a choice of nicotine levels. This allows for the possibility of an endogenous depreciation rate. The current model can be extended to examine the impact of an endogenous depreciation rate on the determinants of cigarette demand.

Since cigarette smoking is injurious to health, a model that considers an endogenous choice of the length of life may also provide insights into consumption patterns of different age groups. In the present study, the consumer's lifetime is assumed to be exogenously given. However, since cigarette smoking is injurious to health, a smoker chooses both the quantity of cigarettes and the expected length of life when deciding how much to smoke. A model that explicitly accounts for this phenomenon may have interesting insights to offer regarding the levels of cigarette consumption by agents of different ages.

This model estimates the impact of addiction information on cigarette consumption after 1979. However, this information was available to the Brown and Williamson Tobacco Company as early as 1962. Another direction for future research would be to use the demand equation from the current model to examine the welfare implications for consumers of the release of addiction information at the initial date of discovery.

The current work does provide a benchmark for the impact of addiction information on the demand for addictive goods. The model proposed here reconciles the competing schools of myopia and rationality by explicitly considering the role of information. It is not meant to explain all possible forms of addiction. However, it does offer some insights into the consumption of a particular addictive good.

APPENDIX A.

SOLUTION TO CHALOUPKA'S STOCK CONSTRAINT

This appendix deals with the details of solving the addictive stock differential equation (2.23). The solution derived here corresponds to equation (2.25) Chapter 2. Equation (2.23) is reproduced here as equation (A1.1).

$$\dot{A}(t) \equiv \frac{\partial A(t)}{\partial t} = C(t) - \delta A(t) \qquad \text{(A1.1)}$$

For any general linear differential equation with non-constant term such as the one given by equation (A1.2), the complete solution is given by the sum of the general solution and the particular solution as in Chiang (1984). This solution is given by equation (A1.3).

$$\dot{y}(t) + uy(t) = W(t) \qquad \text{(A1.2)}$$

$$y(t) = e^{-\delta t}\left[y(0) + \int_0^t W(v)e^{\delta v}dv\right] \qquad \text{(A1.3)}$$

Equation (A1.1) is solved using equation (A1.3) by making the following substitutions:

$$u = \delta \qquad \text{(A1.4)}$$

$$y(t) = A(t) \qquad \text{(A1.5)}$$

$$W(t) = C(t). \qquad \text{(A1.6)}$$

Equations (A1.3), (A1.4), (A1.5) and (A1.7) taken together yield equation (A1.7).

$$A(t) = e^{-\delta t}[A(0) + \int_0^t C(v)e^{\delta v}dv] \qquad \text{(A1.7)}$$

Equation (A1.7) corresponds to the solution presented in the literature review chapter in equation (2.25).

APPENDIX B.

SOLUTION TO THE GENERALIZED DISCRETE STOCK CONSTRAINT

The purpose of this appendix is to provide the details of the solution to the discrete time addictive stock constraint in Chapter 3 given by equation (3.4). This equation is reproduced here as equation (B1.1).

$$A_t = (1-\delta)C_{t-1} + (1-\delta)A_{t-1} \quad \text{(B1.1)}$$

The solution to this equation is obtained by recursion. Consider expressions for A_t for t= 1, 2, 3 etc. Consider the expressions for A_t given by equation (B1.1) for t= 1, 2, 3 and 4. The goal is to notice a pattern and to find a general expression for A_t.

t=1

$$A_1 = (1-\delta)C_0 + (1-\delta)A_0 \quad \text{(B1.2)}$$

t=2

$$A_2 = (1-\delta)C_1 + (1-\delta)A_1 \quad \text{(B1.3)}$$

Equations (B1.2) and (B1.3) can be combined to yield equation (B1.4).

$$A_2 = (1-\delta)C_1 + (1-\delta)[(1-\delta)C_0 + (1-\delta)A_0] \quad \text{(B1.4)}$$

Equation (B1.4) can be simplified and expressed as equation (B1.5).

$$A_2 = (1-\delta)C_1 + (1-\delta)^2 C_0 + (1-\delta)^2 A_0 \quad \text{(B1.5)}$$

For t=3, the expression for A_3 is given by equation (B1.6).

$$A_3 = (1-\delta)C_3 + (1-\delta)A_2 \tag{B1.6}$$

Equation (B1.6) can be further simplified by substituting out for A_2, using equation (B1.5) and gathering like terms. The result is given by equation (B1.7).

$$A_3 = (1-\delta)C_2 + (1-\delta)^2 C_1 + (1-\delta)^3 C_0 + (1-\delta)^3 A_0 \tag{B1.7}$$

For t=4, the expression for A_t is given by equation (B1.8).

$$A_4 = (1-\delta)C_4 + (1-\delta)A_3 \tag{B1.8}$$

Equation (B1.8) can be further simplified by substituting out for A_3 using equation (B1.7) and gathering like terms. The result is given by equation (B1.9).

$$A_4 = (1-\delta)C_3 + (1-\delta)^2 C_2 + (1-\delta)^3 C_1 + +(1-\delta)^4 C_0 + (1-\delta)^4 A_0 \tag{B1.9}$$

The pattern that has been emerging in equations (B1.5), (B1.7) and (B1.9) for A_t, in general, is summarized using summation notation in equation (B1.10).

$$A_t = \sum_{i=1}^{t} (1-\delta)^i C_{t-i} + (1-\delta)^t A_0 \tag{B1.10}$$

In order to transform equation (B1.10) into the solution given by equation (3.5), a change of notation is employed. In equation (B1.10) let j=t-i. For i=1, j=t-1 and for i=t, j=0. This gives rise to equation (B1.11).

$$A_t = \sum_{j=t-1}^{0} (1-\delta)^{t-j} C_j + (1-\delta)^t A_0 \tag{B1.11}$$

Next, using the commutative property of addition, rewrite equation (B1.11) as equation (B1.12).

$$A_t = \sum_{j=0}^{t-1} (1-\delta)^{t-j} C_j + (1-\delta)^t A_0 \tag{B1.12}$$

Replace j with i in equation (B1.12) to get equation (B1.13) which is the desired solution.

$$A_t = \sum_{i=0}^{t-1}(1-\delta)^{t-i}C_i + (1-\delta)^t A_0 \tag{B1.13}$$

APPENDIX C.

SOLUTION TO THE DIFFERENCE EQUATION

The purpose of this appendix is to provide the details of the solution to the second-order linear difference equation (3.46) which is discussed in Chapter 3. This equation is solved in accordance with the procedures outlined by Sargent (1979). The difference equation is reproduced here as equation (C1.1) for the reader's convenience.

$$C_{t-1} - \alpha_1 C_{t-2} - \alpha_2 C_t = \alpha_o + \alpha_3 P_{t-1} + \alpha_4 e_{t-1} + \alpha_5 e_t \qquad \text{(C1.1)}$$

Before attempting to solve equation (C1.1), it is useful to explore the relationship between α_1 and α_2. In particular, the expressions for these two coefficients are given by equations (3.22) and (3.23) which have been reproduced here as equations (C1.2) and (C1.3), respectively.

$$\alpha_1 = \frac{1}{\Omega}[-U_{12}(1-\delta) + \frac{U_{1y}U_{2y}(1-\delta)}{U_{yy}}] \qquad \text{(C1.2)}$$

$$\alpha_2 = \frac{1}{\Omega}[-\beta U_{12}(1-\delta) + \frac{\beta U_{1y}U_{2y}(1-\delta)}{U_{yy}}] \qquad \text{(C1.3)}$$

Equation (C1.3) can be manipulated to show that α_2 equals the product of β and α_1 as follows. Factor β out as a common term, and rewrite equation (C1.3) in terms of α_1. This is demonstrated by equation (C1.4).

$$\alpha_2 = \beta\left[\frac{1}{\Omega}[-U_{12}(1-\delta) + \frac{U_{1y}U_{2y}(1-\delta)}{U_{yy}}]\right] = \beta\alpha_1 \qquad \text{(C1.4)}$$

Solving the Difference Equation

The solution of equation (C1.1) will proceed in four broad steps. First, the homogeneous version of equation (C1.1) will be solved to obtain the complementary function. Next, the particular integral will be obtained by solving the non-homogeneous version of equation (C1.1). The general solution is generated by the simple sum of the complementary function and the particular integral. Finally, initial conditions will be used to determine the values of the exogenous constants in the general solution. The exogenous constants in the general solution will then be replaced by these values to generate the complete solution to equation (C1.1). Finally, the appendix will consider a special assumption which enables one to proceed from the complete solution of equation (C1.1) to the Becker et al. version of this solution.

In keeping with Sargent (1979) to solve equation (C1.1), the algebra of lag operators will be used. Begin by introducing h(t), an abbreviation for the exogenous variables on the right-hand side of equation (C1.1), where h(t) is defined as in equation (C1.5).

$$h(t) \equiv \alpha_o + \alpha_3 P_{t-1} + \alpha_4 e_{t-1} + \alpha_5 e_t \qquad \text{(C1.5)}$$

The modified version of equation (C1.1) is given by equation (C1.6).

$$C_{t-1} - \alpha_1 C_{t-2} - \alpha_2 C_t = h(t) \qquad \text{(C1.6)}$$

Use equation (C1.4) to substitute out for α_2 in equation(C1.6).

$$C_{t-1} - \alpha_1 C_{t-2} - \beta\alpha_1 C_t = h(t) \qquad \text{(C1.7)}$$

Next, equation (C1.7) will be expressed in lag-operator notation where the lag operator L^n is defined in equation (C1.8).

$$L^n X_t \equiv X_{t-n} \tag{C1.8}$$

$$LC_t - \alpha_1 L^2 C_t - \beta\alpha_1 C_t = h(t) \tag{C1.9}$$

Deriving the Complementary Function

In keeping with Sargent, the complementary function is derived by solving the homogeneous version of equation (C1.9). This is given by the following equation:

$$LC_t - \alpha_1 L^2 C_t - \beta\alpha_1 C_t = 0. \tag{C1.10}$$

The characteristic equation that corresponds to equation (C1.10) is obtained by using the substitution stated in equation (C1.11).

$$C_t = \phi^t \tag{C1.11}$$

Equations (C1.10) and (C1.11) yield the auxiliary equation given by equation (C1.12).

$$\phi - \alpha_1\phi^2 - \beta\alpha_1 = 0 \tag{C1.12}$$

The roots of this equation, ϕ_1 and ϕ_2, are given by equations (C1.13) and (C1.14), respectively.

$$\phi_1 = \frac{1-\sqrt{1-4\beta\alpha_1^2}}{2\alpha_1} \tag{C1.13}$$

$$\phi_2 = \frac{1+\sqrt{1-4\beta\alpha_1^2}}{2\alpha_1} \tag{C1.14}$$

The complementary function is given by equation (C1.15) where A_1 and A_2 are exogenous constants that will be determined using initial conditions.

$$C_t = A_1\phi_1^t + A_2\phi_2^t \tag{C1.15}$$

Deriving the Particular Integral

In keeping with Sargent, the particular integral is derived from solving the non-homogeneous difference equation given by (C1.9) for C_t.

$$C_t = \frac{h(t)}{(L - \alpha_1 L^2 - \beta\alpha_1)} \tag{C1.16}$$

The strategy here is to manipulate the denominator in the right hand side of equation (C1.16) to a stage where standard lag operator results can be invoked to express C_t as the weighted sum of the h(t) terms, where the weights are given by the two roots ϕ_1 and ϕ_2.

The denominator in the right hand side of equation (C1.16) is a quadratic in L. The following fact about a quadratic form given by equation (C1.17) can be used to transform equation (C1.16) into equation (C1.18).

$$L^2 + bL + c = (L - \phi_1)(L - \phi_2) = \phi_1\phi_2\left(1 - \frac{L}{\phi_1}\right)\left(1 - \frac{L}{\phi_2}\right) \tag{C1.17}$$

$$C_t = \frac{h(t)}{-\alpha_1\phi_1\phi_2\left(1 - \frac{L}{\phi_1}\right)\left(1 - \frac{L}{\phi_2}\right)} \tag{C1.18}$$

The roots ϕ_1 and ϕ_2 are given by equations (C1.13) and (C1.14), respectively. Next, consider the following notational changes:

$$\phi_1 \equiv \frac{1}{\rho_1} \tag{C1.19}$$

$$\phi_2 \equiv \frac{1}{\rho_2}. \tag{C1.20}$$

Next, use equations (C1.19) and (C1.20) to rewrite equation (C1.18) as equation (C1.21).

$$C_t = \frac{h(t)}{-\alpha_1\left(\frac{1}{\rho_1\rho_2}\right)(1-\rho_1 L)(1-\rho_2 L)} \tag{C1.21}$$

In order to bring some standard lag operator results to bear, equation (C1.21) needs to be manipulated once more. This is done by using an algebraic equivalence given by (C1.22) to rewrite equation (C1.21) as equation (C1.23).

$$\frac{1}{(1-\rho_2 L)(1-\rho_1 L)} = \frac{\rho_2}{(\rho_2-\rho_1)}\frac{1}{(1-\rho_2 L)} - \frac{\rho_1}{(\rho_2-\rho_1)}\left(\frac{-(\rho_1 L)^{-1}}{1-(\rho_1 L)^{-1}}\right) \tag{C1.22}$$

$$C_t = -\frac{\rho_1\rho_2}{\alpha_1}\frac{\rho_2}{(\rho_2-\rho_1)}\left[\frac{h(t)}{(1-\rho_2 L)}\right] + \frac{\rho_1\rho_2}{\alpha_1}\frac{\rho_1}{(\rho_2-\rho_1)}\left[\frac{-(\rho_1 L)^{-1}h(t)}{1-(\rho_1 L)^{-1}}\right] \tag{C1.23}$$

Next, two lag operator results from Sargent are stated as equations (C1.24) and (C1.25).

$$\frac{h(t)}{1-\rho_2 L} = \sum_{j=0}^{\infty}\rho_2^j h(t-j) \tag{C1.24}$$

$$\frac{h(t)}{1-\rho_1 L} = \left[\frac{-(\rho_1 L)^{-1}h(t)}{1-(\rho_1 L)^{-1}}\right] = -\sum_{j=1}^{\infty}\left(\frac{1}{\rho_1}\right)^j h(t+j) \tag{C1.25}$$

Equations (C1.24) and (C1.25) are used to convert equation (C1.23) into equation (C1.26).

$$C_t = \frac{\rho_1\rho_2}{\alpha_1}\frac{\rho_2}{(\rho_1-\rho_2)}\sum_{j=0}^{\infty}\rho_2^j h(t-j) + \frac{\rho_1\rho_2}{\alpha_1}\frac{\rho_1}{(\rho_1-\rho_2)}\left[\sum_{j=1}^{\infty}\left(\frac{1}{\rho_1}\right)^j h(t+j)\right] \tag{C1.26}$$

Finally, use equations (C1.19) and (C1.20) to substitute out for ρ_1 and ρ_2 in equation (C1.26). This yields equation (C1.27) which is the required particular integral.

$$C_t = \frac{1}{\alpha_1\phi_2(\phi_2 - \phi_1)}\sum_{j=0}^{\infty}\phi_2^{-j}h(t-j) + \frac{1}{\alpha_1\phi_1(\phi_2 - \phi_1)}\left[\sum_{j=1}^{\infty}\phi_1^{j}h(t+j)\right] \qquad \text{(C1.27)}$$

Deriving the General Solution

The general solution to equation (C1.1) is obtained by summing the complementary function from equation (C1.15) and the particular integral from equation (C1.27). The general solution is given by equation (C1.28).

$$C_t = A_1\phi_1^t + A_2\phi_2^t + \frac{1}{\alpha_1\phi_2(\phi_2 - \phi_1)}\sum_{j=0}^{\infty}\phi_2^{-j}h(t-j) + \frac{1}{\alpha_1\phi_1(\phi_2 - \phi_1)}\left[\sum_{j=1}^{\infty}\phi_1^{j}h(t+j)\right] \qquad \text{(C1.28)}$$

Obtaining the Complete Solution using Initial Conditions

In keeping with Becker et al., the complete solution to equation (C1.1) is obtained by invoking the following assumptions:

$$C_0 = C^o \qquad \text{(C1.29)}$$

$$A_2 = 0 \qquad \text{(C1.30)}$$

$$h(-s) = 0 \ \forall \ s > 0. \qquad \text{(C1.31)}$$

Equation (C1.29) pins down the value of C at time zero (i.e., it specifies the initial amount of cigarette consumption). Equation (C1.30) eliminates the larger root ϕ_2 from the solution. Equation (C1.31) assumes that the values of the exogenous variables prior to the initial time period do not have any bearing on the solution. Equations (C1.28), (C1.29) and (C1.30) yield equation (C1.32).

$$A_1 = \left(C^o - \frac{1}{\alpha_1 \phi_1 (\phi_2 - \phi_1)} \sum_{j=1}^{\infty} \phi_1^j h(j) \right) \tag{C1.32}$$

When equation (C1.32) is used to substitute out for A_1 in equation (C1.28), the complete solution to equation (C1.1) is obtained. This complete solution is given by equation (C1.33).

$$C_t = \left(C^o - \frac{1}{\alpha_1 \phi_1 (\phi_2 - \phi_1)} \sum_{j=1}^{\infty} \phi_1^j h(j) \right) \phi_1^t + \frac{1}{\alpha_1 \phi_2 (\phi_2 - \phi_1)} \sum_{j=0}^{t} \phi_2^{-j} h(t-j)$$
$$+ \frac{1}{\alpha_1 \phi_1 (\phi_2 - \phi_1)} \left[\sum_{j=1}^{\infty} \phi_1^j h(t+j) \right] \tag{C1.33}$$

Obtaining the Becker et al. Solution to the Difference Equation

The Becker et al. solution to equation (C1.1) can be obtained from equation (C1.33) with the additional assumption that is given by equation (C1.34).

$$\beta = 1 \tag{C1.34}$$

If the rate of time preference β is assumed to equal one, then in this special case alone will the solution to equation (C1.1) take the Becker et al. form. Assuming that β equals one is equivalent to assuming that the roots ϕ_1 and ϕ_2 are reciprocal in nature. The product of ϕ_1 and ϕ_2 can be obtained by considering equations (C1.13) and (C1.14).

$$\phi_1 \phi_2 = \frac{\alpha_2}{\alpha_1} = \beta \tag{C1.35}$$

It is clear from equation (C1.35) that only in the special case of $\beta=1$, will the roots ϕ_1 and ϕ_2 be reciprocal in nature. It is only under this special assumption that equation (C1.33) can be rewritten as the Becker et al. solution given by equation (C1.36).

$$C_t = \left(C^o - \frac{1}{\alpha_1\phi_1(\phi_2 - \phi_1)} \sum_{j=1}^{\infty} \phi_1^j h(j) \right) \left(\frac{1}{\phi_2} \right)^t + \frac{1}{\alpha_1\phi_2(\phi_2 - \phi_1)} \sum_{j=0}^{\infty} \phi_2^{-j} h(t-j)$$

$$+ \frac{1}{\alpha_1\phi_1(\phi_2 - \phi_1)} \left[\sum_{j=1}^{\infty} \phi_1^j h(t+j) \right] \qquad \text{(C1.36)}$$

Assuming that $\beta=1$ has the economic implication of the agent weighting her utility from all time periods equally. It is only under this very restrictive assumption that the Becker et al. solution is obtained.

APPENDIX D.

COMPUTATION OF REGRESSION CONSTANTS

The purpose of this appendix is to discuss the process of recovering the intercept term for each state in a given year. Furthermore, as an example, the appendix will provide a summary of the state and time dummies from regression (iv) in Table 5.4. Finally, the implications of the increasing amount of publicity concerning the cigarette industry in recent years will be discussed.

Table D1.1 presents a summary of the constant term and the state and time dummies from regression (iv) from Table 5.4 (in Chapter 5). Given that the data set is both cross-sectional across states and is comprised of a time-series across the years 1955-1994, a fixed effects model is used. A dummy variable is included for every state except the state of Alabama, and a dummy variable is included for every year except the year 1957. Despite the fact that data from 1955-1957 are available, the regression uses values from 1957-1994 because the tax and price instruments include taxes and prices with a two-period lag.

The default constant corresponds to the intercept for the state of Alabama in the year 1957. The constant term for any state in any given year is simply the sum of the default constant plus the coefficients of the state and time dummies for the year in question. For example, the constant term for the state of Iowa in the year 1958 is given by the sum of the default constant, 59.250, plus the coefficient of the Iowa state dummy, 0.170 plus the coefficient of the time dummy for 1958, 1.411.

These state and time dummies are included in an effort to control for state and time specific effects that may be present. In recent years the tobacco industry has been the focus of close scrutiny by the media. In the process there has been a lot of publicity about the health dangers of consuming cigarettes. These effects are picked up by the time specific dummies, and it is interesting to note that the coefficients of the time specific dummies switch signs from positive to negative in 1984. Unfortunately, these coefficients are not significantly different from zero at the five percent level.

Table D1.1 State and Time Dummy Coefficients from Regression (iv)

Category (State/Year)	Variable Name	Coefficient	(T-ratio)
Alabama	CONSTANT	59.250	(8.414)
Alaska	DUM2	2.734	(1.309)
Arizona	DUM4	-1.683	(-1.227)
Arkansas	DUM5	3.376	(2.529)
California	DUM6	0.608	-0.441
Colorado	DUM8	-1.770	(-1.100)
Connecticut	DUM9	4.259	(2.099)
Delaware	DUM10	-2.166	(-0.945)
District of Columbia	DUM11	17.018	(5.933)
Florida	DUM12	8.743	(5.069)
Georgia	DUM13	2.395	(1.786)
Hawaii	DUM15	-15.922	(-6.85)
Idaho	DUM16	-6.820	(-4.619)
Illinois	DUM17	4.982	(2.847)
Indiana	DUM18	3.567	(2.294)
Iowa	DUM19	0.170	-0.123
Kansas	DUM20	-0.769	(-0.545)
Kentucky	DUM21	-7.606	(-2.71)
Louisiana	DUM22	5.160	(3.677)
Maine	DUM23	8.091	(5.045)
Maryland	DUM24	1.623	-0.965
Massachusetts	DUM25	6.694	(3.731)
Michigan	DUM26	5.483	(3.391)
Minnesota	DUM27	0.919	-0.637
Mississippi	DUM28	-0.479	(-0.366)
Missouri	DUM29	2.955	(1.988)
Montana	DUM30	-0.901	(-0.671)
Nebraska	DUM31	-1.774	(-1.273)
Nevada	DUM32	21.519	(7.309)
New Hampshire	DUM33	30.119	(7.322)
New Jersey	DUM34	6.842	(3.409)

Table D1.1 (Continued)

Category (State/Year)	Variable Name	Coefficient	(T-ratio)
New Mexico	DUM35	-8.194	(-5.320)
New York	DUM36	3.537	(1.996)
North Carolina	DUM37	-10.088	(-2.627)
North Dakota	DUM38	-4.643	(-3.310)
Ohio	DUM39	4.524	-2.930
Oklahoma	DUM40	3.449	(2.513)
Oregon	DUM41	3.389	(2.089)
Pennsylvania	DUM42	3.803	(2.498)
Rhode Island	DUM44	7.187	(4.129)
South Carolina	DUM45	0.270	-0.211
South Dakota	DUM46	-4.698	(-3.386)
Tennessee	DUM47	5.299	(3.696)
Texas	DUM48	0.900	-0.645
Utah	DUM49	-17.316	(-7.755)
Vermont	DUM50	9.197	(5.188)
Virginia	DUM51	-5.550	(-3.267)
Washington	DUM53	-3.917	(-2.361)
West Virginia	DUM54	4.012	-2.830
Wisconsin	DUM55	0.238	-0.171
Wyoming	DUM56	3.527	(2.245)
1958	D58	1.411	(1.086)
1959	D59	6.321	(4.739)
1960	D60	4.836	(3.496)
1961	D61	7.517	(5.671)
1962	D62	5.556	(4.083)
1963	D63	5.846	(4.476)
1964	D64	1.969	(1.481)
1965	D65	4.752	(3.578)
1966	D66	4.612	(3.306)
1967	D67	3.791	(2.735)
1968	D68	1.157	-0.799
1969	D69	2.094	(1.465)

Table D1.1 (Continued)

Category (State/Year)	Variable Name	Coefficient	(T-ratio)
1970	D70	0.449	-0.298
1971	D71	4.147	(2.508)
1972	D72	6.266	(3.665)
1973	D73	3.173	(1.797)
1974	D74	3.421	(1.963)
1975	D75	1.632	-0.931
1976	D76	5.410	(3.072)
1977	D77	1.073	-0.608
1978	D78	1.639	-0.890
1979	D79	1.571	-0.354
1980	D80	1.360	-0.313
1981	D81	1.225	-0.288
1982	D82	1.337	-0.315
1983	D83	0.774	-0.178
1984	D84	-1.473	(-0.331)
1985	D85	-0.062	(-0.014)
1986	D86	-0.176	(-0.039)
1987	D87	-0.440	(-0.096)
1988	D88	-1.483	(-0.321)
1989	D89	-1.677	(-0.356)
1990	D90	-2.943	(-0.610)
1991	D91	-2.822	(-0.581)
1992	D92	-1.069	(-0.210)
1993	D93	-1.077	(-0.208)
1994	D94	-4.895	(-1.006)

APPENDIX E.

SIMULATIONS

According to Glantz et al. (1995), the Brown and Williamson Tobacco Company was aware of the addictive effects of nicotine as early as 1962. They go on to state that this information was not revealed to the public until the Surgeon General's report of 1979. Several states, including the state of Iowa, are currently suing various tobacco firms for violating consumer fraud statutes which require the producer to disclose any adverse effects that their products may have on the consumer. If the Brown and Williamson Tobacco Company had chosen to comply with the consumer fraud statutes, this information would probably have been released by 1963. The purpose of this appendix is to simulate the effects of the release of addiction information in 1963 on cigarette consumption from 1963 to 1987. The next section will briefly discuss the theoretical assumptions under which the simulations were performed. It will also briefly describe the theoretical equation used to perform the simulations. Next, the regression coefficients that are used in the simulations will be reported. The following section will outline the operationalization of the theoretical solution. The subsequent section will report a representative selection of simulation results and discuss their economic implications. The appendix concludes with some of the limitations of the approach used to conduct these simulations.

The Theoretical Basis of the Simulations

The simulations are performed using the closed form solution to the (demand) difference equation that is derived in APPENDIX C. The solution is given by equation (C1.33). This equation is reproduced here for the reader's convenience as equation (E1.1).

$$C_t = A_1\phi_1^t + A_2\phi_2^t + \frac{1}{\alpha_1\phi_2(\phi_2-\phi_1)}\sum_{j=0}^{\infty}\phi_2^{-j}h(t-j) + \frac{1}{\alpha_1\phi_1(\phi_2-\phi_1)}\sum_{j=1}^{\infty}\phi_1^{j}h(t+j) \quad \text{(E1.1)}$$

ϕ_1 and ϕ_2 are the roots of the difference equation given by equation (C1.10). A_1 and A_2 are constants that are to be determined using initial conditions. The solution presented in equation (E1.1) is entirely composed of exogenous variables. However, this equation is not suitable for the purposes of simulation because the empirical estimates (which will be described in a later section) yield an unstable value of ϕ_2. The estimate of ϕ_2 inferred from the regression parameters is greater than unity. Thus, as the value of t increases, ϕ_2^t will explode to plus infinity. This results in simulated solutions of C_t either going to plus infinity or to minus infinity depending upon the sign of A_2. However, the regression estimates do yield a stable value of ϕ_1. In order to obtain reasonable estimates from the simulations, the set of solutions defined by equation (E1.1) is limited to the subset of stable solutions. In other words, the unstable root ϕ_2 is eliminated from the solution by assuming that A_2=0. In addition, it is assumed that the values of the exogenous variables prior to the initial time period (t=0) do not effect the values of consumption at any time t (C_t). The formal statement of this assumption is provided by equation (C1.31). These two assumptions transform equation (E1.1) into equation (E1.2) which is used to perform the simulations.

$$C_t = \left(C^o - \frac{1}{\alpha_1 \phi_1 (\phi_2 - \phi_1)} \sum_{j=1}^{\infty} \phi_1^j h(j) \right) \phi_1^t + \frac{1}{\alpha_1 \phi_2 (\phi_2 - \phi_1)} \sum_{j=0}^{t} \phi_2^{-j} h(t-j)$$

$$+ \frac{1}{\alpha_1 \phi_1 (\phi_2 - \phi_1)} \left[\sum_{j=1}^{\infty} \phi_1^j h(t+j) \right] \qquad \text{(E1.2)}$$

C^o is the initial value of consumption, and h(t) is an abbreviation for the exogenous variables as defined in equation (C1.5).

Regression Estimates Used to Perform the Simulations

Estimates of the parameters that appear in equation (E1.2) are inferred from the estimates of the regression coefficients. The specific model used for the purposes of these simulations is a rational addiction model without structural breaks that is estimated over the period 1979-1994. The use of a rational addiction model without structural breaks is based on the empirical findings (reported in Table 5.4) of a switch from a myopic to a rational regime after the release of addiction information. The regression is run over the subset 1979-1994 because the goal is to transport the consumption patterns that have evolved since the release of addiction information back to 1963. Table E1.1 reports the estimates from model (iv). Model (iv) is chosen to perform the simulations because it contains the most exhaustive set of instruments.

Operationalizing the Theoretical Solution

In order to use equation (E1.2) to simulate historical values of consumption in the presence of addiction information, the estimates in Table E1.1 are used to infer estimates of the parameters in equation (E1.2). Table (E1.1) reports estimates of the rational addiction model without structural breaks for the period 1979-1994. Asymptotic t-ratios are in parentheses. The observed signs of the estimates of all the coefficients conform to their predicted directions which are discussed in Chapters 3 and 4. All the variables except future consumption (C_{t+1}) are significant at the one percent level of significance. C_{t+1} is significant at the five percent significance level. The value of α_1 is given by the estimate of the coefficient of C_{t-1}. The value of α_1 for the simulations is given by the estimate of the coefficient of C_{t-1}. ϕ_1 and ϕ_2 are given by equations

Table E1.1 Regression Estimates Used in the Simulations

RHS Variables	Coefficient (iv)
C_{t-1}	0.389
	(5.07)
C_{t+1}	0.206
	(2.524)
P_t	-29.065
	(-6.167)
INC_t	0.131
	(4.861)
$SDTIMP_t$	-4.542
	(-2.652)
$SDTEXP_t$	-82.766
	(-6.187)
$LDTAX_t$	-64.759
	(-6.11)
R^2	0.979
β	0.530
r	0.888
N	788

(C1.13) and (C1.14) which are reproduced here as equations (E1.3) and (E1.4) for the reader's convenience. Note that the value of ϕ_2 exceeds one, while the value of ϕ_1 is less than one. In other words ϕ_2 is the unstable root, and ϕ_1 is the stable root.

$$\phi_1 = \frac{1-\sqrt{1-4\beta\alpha_1^2}}{2\alpha_1} = 0.225626 \qquad \text{(E1.3)}$$

$$\phi_2 = \frac{1+\sqrt{1-4\beta\alpha_1^2}}{2\alpha_1} = 2.343351 \qquad \text{(E1.4)}$$

Equation (E1.2) uses an infinite series in all the summations. However, theoretically speaking, ϕ_1^t and $\frac{1}{\phi_2^t}$ go to zero after a large enough value of t is reached because ϕ_1 is less than one and ϕ_2 is greater than one. Given the estimates in equations (E1.3) and (E1.4), ϕ_1 raised to the fourth power is 0.00 and $\frac{1}{\phi_2^t}$ raised to the sixth power is 0.00. Each of the summations is taken over a horizon comprised of four time periods. The complete theoretical expression for h(t) is given by equation (C1.5). Its operationalized equivalent is given by equation (E1.5).

$$h(t) \equiv \alpha_o + \alpha_3 P_{t-1} + \alpha_6 INC_{t-1} + \alpha_7 SDTIMP_{t-1} + \alpha_8 SDTEXP_{t-1} + \alpha_9 LDTAX_{t-1} \qquad \text{(E1.5)}$$

The constant term α_o varies across states and years. For any given state in any given year, it is given by the estimate of the default constant from the regression used plus the sum of the estimates of the coefficients of the state and time dummies of the state and year in question. It is this difference among states that allows a separate consumption series to be simulated for each state. The estimates of the coefficients α_3, α_6, α_7, α_8, and α_9 are reported in Table (E1.1) as the coefficients on P_{t-1}, INC_{t-1}, $SDTIMP_{t-1}$, $SDTEXP_{t-1}$ and $LDTAX_{t-1}$, respectively. The values for these exogenous variables themselves are taken from their respective data series in each state beginning in 1963.

Simulation Results and Implications

The above procedure was implemented for forty-one different states and the District of Columbia. Simulations were not performed for states with missing data. The average simulated values for the U.S. based on the forty-two simulations are reported in Table E1.2. This table also reports the average per capita consumption levels that were actually observed across the forty-one states and the District of Columbia. In general average simulated series consumption is less than average observedconsumption. The average simulated values exceed the average observed consumption levels for the years 1963-1964 and 1968-1971. In general, the simulated consumption levels for most states exceeded the actual consumption levels for the years 1963-1964. However, for the years 1968-1971, most states had simulated consumption levels that were lower than the actual consumption levels in those states. There were a few states whose simulated levels greatly exceeded the actual consumption levels during these years. Thus, the U.S. average simulated consumption for the years 1968-1971 exceeds actual average consumption due to the dominance of a few states.

A representative sample of the simulations results from five states is presented in Tables E1.3 through E1.7. The fitted values based on model (iv) from Chapter 5 are included as a benchmark. The results for the state of Alabama are presented in Table E1.3. The Alabama results are quite unique compared to the rest of the states because for the state of Alabama the simulated consumption series suggests that, on average, a release of addiction information would lead to a level of consumption greater than the level of consumption observed in the absence of addiction information. This does not agree with the intuition that the release of addiction information would prompt people to smoke less because they would be afraid to get hooked. However, the state of Alabama is the only state in which simulated consumption exceeds actual consumption to such an extent.

The majority of states (Tables E1.4 -E1.7) have simulated consumption series that indicate the level of consumption is reduced after the dissemination of addiction information. This .suggests that the release of addiction information causes people to smoke less than if they were unaware of the additive potential of cigarettes. Critics may argue that most smokers discover for themselves that cigarettes are addictive, and thus, the impact of addiction information is being overstated. However, this study contends that an addict who adjusts current consumption levels to compensate for the effects of past consumption need not necessarily consider the future implications of current consumption. On the other hand, if the agent is explicitly informed of the future consequences of current consumption, then a rational agent would pick his level of current consumption while keeping its future effects in mind.

The simulation results must be interpreted with the following limitations in mind. The use of actual data from 1962-1987 for the exogenous variables assumes that if tobacco firms admitted that cigarettes were addictive they would not compensate in any way for this release of information. For example, using the historic price series suggests that cigarette firms would not compensate for the impact of addiction information on consumers by lowering

Table E1.2 Average Simulated Vs. Average Actual Consumption in the U.S.

Year	Average Simulated Consumption[a]	Average Actual Consumption[a]	Difference[b]
1963	133	127	6
1964	125	123	2
1965	124	125	-1
1966	124	126	-2
1967	124	126	-2
1968	125	123	2
1969	125	123	2
1970	124	120	4
1971	124	123	1
1972	124	127	-3
1973	127	129	-2
1974	129	132	-3
1975	130	133	-3
1976	127	136	-9
1977	125	136	-11
1978	124	136	-12
1979	125	134	-9
1980	123	134	-11
1981	125	135	-10
1982	126	133	-7
1983	122	128	-6
1984	115	122	-7
1985	113	121	-8
1986	111	118	-7
1987	111	115	-4

[a] All consumption figures are reported in packs.
[b] The Difference is computed by taking the difference between average simulated and average actual consumption.

Table E1.3 Simulated Vs. Actual Consumption in Alabama

Year	Fitted Consumption[a]	Simulated Consumption[a]	Actual Consumption[a]	Difference[b]
1963	98	121	94	27
1964	95	119	95	24
1965	100	120	99	21
1966	100	119	96	23
1967	99	119	96	23
1968	92	115	88	27
1969	90	114	90	24
1970	89	112	90	22
1971	92	112	95	17
1972	100	116	101	15
1973	103	120	103	17
1974	108	124	108	16
1975	110	126	112	14
1976	116	123	116	7
1977	117	123	117	6
1978	118	123	123	0
1979	124	125	121	4
1980	123	122	123	-1
1981	122	121	120	1
1982	120	121	119	2
1983	117	117	116	1
1984	113	112	113	-1
1985	113	109	115	-6
1986	113	109	116	-7
1987	112	110	114	-4

[a] All consumption figures are reported in packs.
[b] The Difference is computed by taking the difference between simulated and actual consumption.

Table E1.4 Simulated Vs. Actual Consumption in Connecticut

Year	Fitted Consumption[a]	Simulated Consumption[a]	Actual Consumption[a]	Difference[b]
1963	149	149	156	-7
1964	145	133	144	-11
1965	145	134	147	-13
1966	149	138	145	-7
1967	149	143	146	-3
1968	148	147	143	4
1969	154	150	145	5
1970	125	118	120	-2
1971	114	103	118	-15
1972	108	90	111	-21
1973	106	89	109	-20
1974	108	93	112	-19
1975	111	97	110	-13
1976	116	100	113	-13
1977	116	102	117	-15
1978	121	105	118	-13
1979	117	109	117	-8
1980	118	109	118	-9
1981	117	110	116	-6
1982	117	112	115	-3
1983	115	110	114	-4
1984	109	103	113	-10
1985	108	101	111	-10
1986	109	102	109	-7
1987	106	105	109	-4

[a] All consumption figures are reported in packs.
[b] The Difference is computed by taking the difference

Table E1.5 Simulated Vs. Actual Consumption in Iowa

Year	Fitted Consumption[a]	Simulated Consumption[a]	Actual Consumption[a]	Difference[b]
1963	118	122	115	7
1964	114	114	110	4
1965	115	112	116	-4
1966	114	108	108	0
1967	110	105	114	-9
1968	106	101	109	-8
1969	106	101	108	-7
1970	107	105	109	-4
1971	111	107	108	-1
1972	112	106	109	-3
1973	113	110	111	-1
1974	116	113	116	-3
1975	119	115	121	-6
1976	126	113	124	-11
1977	125	111	126	-15
1978	126	111	127	-16
1979	125	113	124	-11
1980	128	111	125	-14
1981	123	113	133	-20
1982	123	110	116	-6
1983	115	104	116	-12
1984	110	97	111	-14
1985	108	94	109	-15
1986	105	91	104	-13
1987	101	89	101	-12

[a] All consumption figures are reported in packs.
[b] The Difference is computed by taking the difference

Table E1.6 Simulated Vs. Actual Consumption in Kentucky

Year	Fitted Consumption[a]	Simulated Consumption[a]	Actual Consumption[a]	Difference[b]
1963	133	135	126	9
1964	134	131	127	4
1965	139	134	129	5
1966	147	140	134	6
1967	150	144	139	5
1968	154	149	143	6
1969	158	153	146	7
1970	167	162	156	6
1971	177	166	164	2
1972	189	172	179	-7
1973	197	176	202	-26
1974	209	176	212	-36
1975	211	172	223	-51
1976	218	165	231	-66
1977	217	160	229	-69
1978	215	156	225	-69
1979	209	154	215	-61
1980	203	147	215	-68
1981	201	145	210	-65
1982	196	143	211	-68
1983	189	138	201	-63
1984	182	131	183	-52
1985	177	129	182	-53
1986	175	128	180	-52
1987	175	130	171	-41

[a] All consumption figures are reported in packs.
[b] The Difference is computed by taking the difference

Table E1.7 Simulated Vs. Actual Consumption in Minnesota

Year	Fitted Consumption[a]	Simulated Consumption[a]	Actual Consumption[a]	Difference[b]
1963	108	114	113	1
1964	109	107	105	2
1965	108	108	109	-1
1966	113	110	111	-1
1967	114	112	114	-2
1968	113	113	114	-1
1969	115	114	112	2
1970	108	109	104	5
1971	108	108	116	-8
1972	113	103	97	6
1973	101	104	107	-3
1974	109	106	111	-5
1975	111	108	112	-4
1976	117	106	117	-11
1977	117	105	117	-12
1978	119	106	119	-13
1979	118	108	118	-10
1980	120	107	118	-11
1981	121	111	121	-10
1982	120	114	119	-5
1983	116	109	113	-4
1984	111	102	111	-9
1985	109	101	113	-12
1986	108	96	104	-8
1987	100	94	109	-15

[a] All consumption figures are reported in packs.
[b] The Difference is computed by taking the difference

prices. In addition, these simulations are based upon the assumption that the release of addiction information by cigarette firms would not prompt any government policies designed to curb consumption. Also, it should be pointed out that the annual dummy coefficients for the years 1962 -1979 are not available because the regression is run on a subset of the data from 1979-1994. This is equivalent to performing the simulations under the assumption that there were no significant annual effects in the years 1963-1979. This assumption is questionable because other studies by Warner (1977) and Hamilton (1972) suggest that health warnings by the Surgeon General in the early sixties would cause consumption to decrease. In light of this fact, one might argue that the release of addiction information may have caused a further decrease in consumption and that the present simulations overstate the values of consumption that may have been observed during the years 1963-1987.

Clearly, these simulations have many limitations which need to be explored at a much greater depth before credible estimates in which one can place a great deal of confidence are obtained. However, the discussion of many of the problems associated with trying to simulate from an unstable difference equation that is given in this study provides a starting point for possible further research into this issue.

APPENDIX F

VARIABLE DEFINITIONS

Table F1.1 Variable Definitions

Variable	Description
C_t	Per capita cigarette consumption in packs in fiscal year t as obtained from state cigarette excise tax-paid sales.
P_t	Average retail price of year t and t-1 as reported in November of each year in 1982-84 dollars.
INC_t	Average of per capita income in year t and t-1 in 1982-84 dollars.
$SDTIMP_t$	Index which measures casual (import) smuggling incentives . This index is a weighted average of the tax differential between the importing state and the surrounding lower tax states, with weights based on the border populations. A computational formula is given by equation (4.5).
$SDTEXP_t$	Index which measures casual (export) smuggling incentives . This index is a weighted average of the tax differential between the exporting state and the surrounding lower tax states, with weights based on the border populations. A computational formula is given by equation (4.6).
$LDTAX_t$	Index which measures the incentives to commercially smuggle cigarettes from Kentucky, Virginia and North Carolina to any state with a lower cigarette excise tax rate within a thousand miles. This index is positively related to the difference between the state's excise tax and the excise taxes of the long-distance exporting states. The computational formulas are given by equations (4.7), (4.8) and (4.11).
INFO	A structural break dummy variable which takes on a value of zero for the years 1955 -1978 and one for the years 1979-1994.
T_i	The annual state cigarette excise-tax in state i in 1982-84 dollars.
POP_i	The annual intercensal estimate of population in state i.
K_{ij}	The border population of state i living within twenty miles of state j.

Table F1.1 (continued)

Variable	Description
Z_{NC}	A weight that is positively related to the ratio of the value added from tobacco production in the state of North Carolina to the sum of the value added from tobacco production in the states of North Carolina and Virginia. A computational formula is provided by equation (4.9).
Z_{VA}	A weight that is positively related to the ratio of the value added from tobacco production in the state of Virginia to the sum of the value added from tobacco production in the states of North Carolina and Virginia. A computational formula is provided by equation (4.9).

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IMAGE EVALUATION TEST TARGET (QA-3)

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