Published in final edited form as:

Contrib Econ Analysis Policy. 2006 March 17; 5(1): 1–22.

Modeling Addictive Consumption as an Infectious Disease*

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Abstract

The dominant model of addictive consumption in economics is the theory of rational addiction. The addict in this model chooses how much they are going to consume based upon their level of addiction (past consumption), the current benefits and all future costs. Several empirical studies of cigarette sales and price data have found a correlation between future prices and consumption and current consumption. These studies have argued that the correlation validates the rational addiction model and invalidates any model in which future consumption is not considered. An alternative to the rational addiction model is one in which addiction spreads through a population as if it were an infectious disease, as supported by the large body of empirical research of addictive behaviors. In this model an individual's probability of becoming addicted to a substance is linked to the behavior of their parents, friends and society. In the infectious disease model current consumption is based only on the level of addiction and current costs. Price and consumption data from a simulation of the infectious disease model showed a qualitative match to the results of the rational addiction model. The infectious disease model can explain all of the theoretical results of the rational addiction model with the addition of explaining initial consumption of the addictive good.

Keywords

addictive consumption; cigarettes; simulation; infectious disease

I. Introduction

The consumption of addictive goods has drawn much attention from economists. Addictive consumption differs from non-addictive consumption because past consumption affects current consumption. Consumption of an addictive good by an individual in one period has a direct effect on that individual's choice of the quantity of the addictive good demanded in the next period. In contrast, consumption of a non-addictive good in one period has no direct effect on the quantity of the good demanded in the next period. Addictive consumption has been previously modeled in two ways: myopic demand and rational addiction.

Myopic models of addictive consumption have been developed (see (Pollak, 1970) for example) in which past consumption enters the utility function so that past consumption has a positive effect on current demand. These models recognized the addictive properties of certain goods such as cigarettes, alcohol and other drugs, but said little about the dynamic behavior of addicts, such as binge consumption (consumption of a large amount of the

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addictive good in a relatively short period of time), and did not describe the process by which individuals become addicted.

Models of rational addiction have provided significant insights into the dynamics of addictive consumption by describing the dynamics around steady state consumption that previous myopic models did not. The rational addiction framework, as originally proposed by Becker and Murphy (Becker and Murphy, 1988) showed how an individual who already had an established addiction with a set of stable, forward looking preferences will remain an addict. There are, however, some well known limitations in the rational addiction framework, most notably that it does not explain initiation (Orphanides and Zervos, 1995). Several extensions have been proposed to the model to try and deal with this limitation while preserving the assumption of forward looking rational behavior with a stable set of preferences (Clarke, 2000; Dockner and Feichtinger, 1993; Feichtinger, 1992; Goldbaum, 2000; Grossman, et al., 1998; Orphanides and Zervos, 1994; Orphanides and Zervos, 1995; Wirl and Feichtinger, 1995; Xu, 2002). (Some of these extensions did depart from the concept of stable preferences, but preserved the forward looking nature of the model (Feichtinger, et al., 1997; Laibson, 2001; Orphanides and Zervos, 1994).) These extensions have created an increasing level of complexity in the theory.

We propose a new myopic model that treats addiction as an infectious disease. This model does not require forward looking rational behavior and avoids the complex modifications that have been proposed for the rational addiction model. Individuals learn to be addicts (become infected) through contact with environmental factors such as friends, family members and society in general. In the model, an individual's probability of becoming addicted is positively related to the consumption status of their parents, peers and the prevalence of consumption in the general population. This learning process is similar to a social contagion that has been modeled in investment behavior (Lux, 1995), strategies in repeated games (Morris, 2000) and the economics of social interaction (Manski, 2000). The infectious disease model explains the same dynamics around steady state consumption as the rational addiction model and adds a more complete description of the process by which individuals become addicted (infected) than the current extensions of the rational addiction model.

Previous empirical work to test the rational addiction model (Becker, et al., 1994) (Chaloupka, 1991) showed that it was consistent with the observed positive correlation between current consumption and future consumption of cigarettes. This observation was used to argue that it is necessary to have rational, forward looking behavior in order to describe the pattern of consumption of an addictive good. To test this assumption, we used the infectious disease model to generate a set of price and consumption values that do not reflect any forward looking behavior. We then fit this simulated "data set" with the rational addiction model using the same econometric techniques that were originally used to test the rational addiction model. The rational addiction model provided a good fit to the data we simulated with our infectious disease model and exhibits a correlation between current and future consumption. This result shows that the correlation between current and future behavior that was used to argue for the presence of rational behavior among addicts is necessary, but not sufficient, to prove the existence of rational behavior.

The theoretical and simulation results of the infectious disease model show that it is a viable alternative to the rational addiction model that not only explains the behavior of established addicts, but also the social process that leads individuals into addiction.

II. Modeling Addiction as an Infectious Disease¹

There is a substantial literature that finds that cigarette and alcohol demand, in particular the decision to initiate consumption, depends on many factors related to an individual's environment. This research has found that the initial decision to initiate depends on the consumption behavior habits of parents and peers as well as the level of consumption encountered in society by way of general interaction with other individuals, advertising, legal restrictions on consumption, and movies (Cook and Moore, 2001; Fichtenberg and Glantz, 2002; Krugman, et al., 2005; Sargent and Dalton, 2003; US Department of Health and Human Services, 1989; US Department of Health and Human Services, 1994; US Department of Health and Human Services, 2000).

Three reports from the US Surgeon General provide a comprehensive analysis of this literature (US Department of Health and Human Services, 1989; US Department of Health and Human Services, 1994; US Department of Health and Human Services, 2000). The 1994 Surgeon General's report surveyed 27 studies of smoking initiation (US Department of Health and Human Services, 1994) (Table 1). A majority of the studies found evidence that factors such as family smoking, adult influences, peer use and school influences had positive effects on smoking initiation. Additionally, more recent work (Charlesworth and Glantz, In Press; Sargent and Dalton, 2003) has found that images of smoking in the movies have a large positive effect on the probability of an adolescent becoming a smoker. Empirical work has shown that environmental or contextual variables are significant in evaluating tobacco control policies (Fichtenberg and Glantz, 2002).² There has also been considerable research on the effect of advertising on consumption (for example (Carson, et al., 2005; Krugman, et al., 2005)) that has no role in current economic models of addiction. While the empirical literature has confirmed the existence of the advertising and environmental effects, the infectious disease model developed below is the first to incorporate the environmental effects in a theoretical model of addictive consumption.

Consider a concave utility function, $U_{i,t}$, that depends on $y_{i,t}$ (consumption of nonaddictive goods) and $c_{i,t}$ (current consumption of the addictive good) and also on past consumption, the level of smoking of the $l \neq i$ individuals in the N member society, and a binary function $I_{i,t}(\dots)$, that indicates whether an individual has been infected or not (i.e., smokes) that is equal to 1 if they have been infected and 0 otherwise.

$$U_{i,t} = F(y_{i,t}, c_{t-1,i}, c_{t,i}, \sum_{l \neq i}^N c_{l,t}, I_{i,t}(\dots)) \quad (1)$$

An individual's probability of becoming addicted to cigarettes (of becoming infected), $\phi_{i,t}$, is positively related to the smoking status of their parents, friends and society in general so that:

¹Both the rational addiction and the new infectious disease model proposed here are general models that apply to any addictive good. The discussion of the two models will focus on the demand for cigarettes for ease of exposition, ease of comparison with the empirical studies and because cigarettes are the leading cause of preventable death in the world and thus have the most important policy implications.

²There has been substantial work within economics on peer effects in models of addictive and nonaddictive consumption (Becker, 1992). Our model is the first to expand peer effects in an addictive model to include parents and society in general.

$$I_{i,t} = I_{i,t-1} + \begin{cases} 0 & \text{if } \phi_{i,t} > r_{i,t} \sim U[0, 1] \\ 1 & \text{if } \phi_{i,t} \leq r_{i,t} \sim U[0, 1] \end{cases} \quad (2)$$

In which $\phi_{i,t}$ is the probability that an individual will become a smoker in period t and $r_{i,t}$ is a random draw for each individual in each time period to determine if they have become “infected” or not. If $\phi_{i,t}$ is greater than $r_{i,t}$ then the individual begins to demand cigarettes according to the demand function implicit in the utility function in equation (1) $\phi_{i,t}$ and its change over time will vary from individual to individual representing different environments and tolerances for societal pressures. The individual also continues to demand cigarettes (ie $I_{i,t} = 1 \forall t$ while $c_t > 0$).

Lagged consumption, $c_{i,t-1}$ enters the utility function directly (since $c_{i,t-1}$ is dependent upon $c_{i,t-2}$ all past consumption and the level of the individual's addiction is reflected in $c_{i,t-1}$):

$$U_{i,t} = \alpha_i y_{i,t} + I_{i,t}(\dots) [\beta_i \ln(c_{i,t-1} - \omega_i) \ln(c_{i,t}) - \gamma_i(c_{i,t-1} + c_{i,t}) - \theta_{i,t} \left(\frac{c_{i,t}}{\sum_{l \neq i}^N c_{l,t}} \right)] \quad (3)$$

In this formulation $y_{i,t}$ is a normal good and numeraire, $I_{i,t}$ is the indicator function discussed above and $c_{i,t}$ is consumption of an addictive good (cigarettes). Utility from consumption is positively related to consumption in the prior period and β_i , the marginal benefit of the next cigarette not conditioned by prior consumption. Utility from consumption is negatively related to ω_i which is negatively related to the strength of an individual's addiction; a health cost γ_i ³ and a social effect which is a function of the parameter $\theta_{i,t}$ and the level of smoking

by the rest of society, $\sum_{l \neq i}^N c_{l,t}$.⁴ An individual's specific social setting is included through the parental and peer effects on $I_{i,t}$ and the effects of society have effects, through total societal prevalence, on $I_{i,t}$ and $U_{i,t}$.

As will be seen below, this utility function implies one stable and one unstable steady state, just as in the rational addiction model. Two steady states are necessary to properly explain the behavior of addicts. More steady states can be found with more complex utility functions, but add no additional insight into the model. Additional stable and unstable steady states would simply imply additional levels of potential addiction as opposed to the two described in this case.

We use a one period budget constraint in which $M_{i,t}$ is annual income and $P_{c,t}$ is the money price of the addictive good.

³We assume that the negative health effects of smoking in period t are completely depreciated in period $t+2$. This is a simplification for ease of exposition. Adding a more gradual depreciation of the health stock would be a minor alteration to the model and would not materially change any of the results.

⁴As the number of smokers in society goes to 0, the social effect goes to infinity. A different formulation could place a limit on the social effect, but as a more complex form will add little insight into the model, the simple form is used for ease of exposition.

$$M_{i,t} = y_{i,t} + P_{c,t} c_{i,t} \quad (4)$$

Maximizing equation (3) subject to the budget equation (4) with respect to $c_{i,t}$ and letting

$\sum_{i \neq t}^N c_{i,t} = S_{i,t}$ for ease of exposition, provides the individual demand for the addictive good in period t .

$$c_{i,t} = \text{Max} \left\{ 0, \frac{\beta_i \text{Ln}(c_{i,t-1}) - \omega_i}{(\alpha_i P_{c,t} + \gamma_i + \frac{\theta_{i,t}}{S_{i,t}})} \right\} \quad (5)$$

In Figure 1, AA represents the line $c_{i,t-1} = c_{i,t}$ and BB is equation (5) when all but $c_{i,t-1}$ and $c_{i,t}$ is held constant. Points on BB that are below AA imply that consumption is falling; points on BB above AA imply increasing consumption. The shape of BB given by equation (5) provides two non-zero steady states in which past consumption is equal to current consumption s_1 and s_2 , but only s_2 is stable. Any consumption in period t below s_1 will lead to lower consumption in period $t+1$, consumption in period t between s_1 and s_2 will lead to higher consumption in period $t+1$ and consumption in period t greater than s_2 will lead to lower consumption in period $t+1$. These dynamics make s_1 the critical level of consumption, above which individuals become addicted. These are the same dynamics exhibited by the rational addiction model (Becker and Murphy, 1988).

The strength of an individual's addiction is defined by the shifting parameter ω_i . Lower values of ω_i characterize a stronger addiction. A lower value of ω_i will shift BB to the left, reducing the critical level of consumption, s_1 needed to become addicted to the substance. Allowing ω_i to vary by individual allows for some individuals to experiment with addictive goods yet not become addicts, while others experimenting with the same level of the substance become immediately addicted. For example, an individual with a low value of ω_i will have a lower value of s_1 than an individual with a high value of ω_i . The lower value of s_1 means that a lower level of consumption is required for the individual to become addicted and consume at the unstable steady state or consume along the path above s_1 that will lead to the stable steady state consumption level s_2 .

The full price of the addictive good is $\alpha_i P_{c,t} + \gamma_i + \frac{\theta_{i,t}}{S_{i,t}}$, which depends on the marginal utility of the normal good, the money price of $c_{i,t}$ in period t , the marginal health cost (which is constant across time), and the marginal social effect in period t .⁵ $\theta_{i,t}$ can be viewed as a policy variable that increases with smokefree workplace ordinances, effective anti-smoking media campaigns, and any other government regulation or social norm changes that reduce the social acceptability of cigarettes. As more people consume the addictive good, the social effect is reduced which raises the overall demand for the good.

The short run money price elasticity⁶ implied by (5), assuming that $c_{i,t}$ is greater than zero is:

⁵The social effect could obviously be altered so that at some level of C_t there is an actual social benefit to consuming the addictive good. This alteration is purely a monotonic transformation of the social effect formulation as written and thus will not affect the results here.

⁶Since these are short run elasticities, no steady state assumption is required.

$$\eta_{ID,P} = - \frac{\alpha_i P_{c,t}}{\alpha_i P_{c,t} + \gamma_i + \frac{\theta_{i,t}}{S_{i,t}}} \quad (6a)$$

and the short run elasticity with respect to the social price is:

$$\eta_{ID,\theta} = - \frac{\theta_{i,t}}{\alpha_i P_{c,t} + \gamma_i + \frac{\theta_{i,t}}{S_{i,t}}} \quad (6b)$$

An increase in either price in period t shifts curve BB downwards, reducing the stable steady state s_2 and raising the unstable steady state s_1 . A price increase then reduces current consumption, steady state consumption, and has the potential to put consumption on a decreasing path. In fact, a price increase that is large enough to shift BB entirely below AA would create a situation in which the only steady state of consumption was zero consumption.

The long run elasticities take into account the individual's own reaction to price changes, the reaction of the smokers around them and the changed probability of any nonsmoker becoming a smoker. If, for example, a price increase causes one individual's consumption to fall below the unstable steady state, then they will quit. With the herd effects of the infectious disease model, one individual quitting has two effects on the rest of society. First, smokers will perceive a higher social effect to smoking because there will be less smoking in society and, second, the probability that a nonsmoker will become a smoker will be reduced.

III. Comparison of the Infectious Disease and Rational Addiction Models

The rational addiction model is currently the dominant model of addictive consumption in economics, so a comparison of the rational addiction model with the infectious disease model will highlight the contribution of this new model of addictive consumption. The infectious disease and rational addiction models both involve utility maximization, but are based upon different sets of assumptions (Table 2). The two most important differences in assumptions are the infectious nature of the initial consumption in the infectious disease model and the forward looking behavior of the rational addiction model. The importance of the assumption regarding the infectious nature of the addictive consumption is that it specifically explains the initiation of addictive consumption and the spread of the consumption. The importance of the assumption of forward looking behavior is that prior myopic models were unable to explain the dynamic behavior of established addicts that incorporating forward looking preferences could. The infectious disease model, can however, explain these dynamics so the need for the assumption regarding forward looking behavior is reduced.

While both the rational addiction and the infectious disease models explain much observed behavior of addicts, the infectious disease model allows for a greater understanding of addictive consumption because it allows for the social effects associated with smoking initiation and consumption. The infectious disease model also allows for the social effects of smoking on both the smoker (perceived levels of social effect) and the nonsmoker (herd effects, probability of becoming a smoker). Due to the large body of literature that supports the existence of the social effects of smoking (US Department of Health and Human Services, 1989; US Department of Health and Human Services, 1994; US Department of

Health and Human Services, 2000), it is important that any model that analyzes tobacco control policies (or policies aimed at controlling the use of other harmfully addictive goods), include these effects.

IV. Forward Looking Preferences with Infectious, Addictive Goods

In theory, both the infectious disease and social effect features of the infectious disease model presented here could be added to the rational addiction framework, by maximizing the utility function of the infectious disease model over multiple time periods. Since the social effect component of the infectious disease model is simply another price, social effects could be added to the rational addiction model. Making these additions, however, leads to predictions for the behavior of individuals who are not yet addicted that are inconsistent with observable data.

Consider a nonsmoker with a forward looking utility function similar to equation (5) but encompassing two time periods. A similar formulation is considered in the rational addiction framework that considers peer pressure (Becker, 1992). The forward looking utility function would include estimates of $\phi_{i,t}$ and $\phi_{i,t+1}$. If the individual is in a high risk situation, (an increasing value of ϕ_i) for example their parents and friends all smoke, or estimate that they will soon have a high risk of becoming a smoker (for example, by viewing many movies that include smoking) and assuming that an addiction is not desirable, the rational response, for individual's with an already high propensity to become addicted, would be to remove themselves from the situation in an attempt to reduce the probability that they will become an addict. While a decision for a teenager to remove themselves from their parents obviously has many other dimensions than those related to smoking, choosing not to view movies with significant levels of smoking is a simple economic decision with a seemingly small marginal cost, that the teenager could make, which they clearly are not.

Adding incomplete information to a rational addiction model with an infectious disease component would seem to be a potential resolution to this inconsistency between behavior and prediction. Incomplete information as proposed by Orphanides and Zervos (1995) would not, however, serve this purpose. Orphanides and Zervos explicitly model initiation through experimentation. They predict that individuals with a naturally high probability of becoming addicted and the belief that they have a low probability of becoming addicted, are likely to become addicted. In other words, in this modification of the rational addiction model, an individual will become an addict if they underestimate their innate likelihood of becoming an addict.

The idea that individuals experiment with addictive goods because they underestimate their natural likelihood of becoming an addict is refuted by the positive correlation discussed above between parents who smoke and children who smoke (US Department of Health and Human Services, 1989; US Department of Health and Human Services, 1994; US Department of Health and Human Services, 2000). Assuming that an individual knows that his parent is addicted to cigarettes, an individual should then condition his expectation regarding his own natural likelihood of becoming an addict on this information. Individuals with parents who are addicts would then be more likely to overestimate their own likelihood of becoming an addict, because they know that they may have a natural predisposition to becoming an addict. Given this overestimation of an individual's own likelihood of becoming an addict, an individual's decision to experiment with cigarettes would be negatively related to his parents addiction, which is not the case (US Department of Health and Human Services, 1989; US Department of Health and Human Services, 1994; US Department of Health and Human Services, 2000). Thus, adding incomplete information to

the forward looking model that incorporates the infectious disease utility function does not resolve the inconsistencies between the theoretical results and observable data.

V. Simulation Experiment

The infectious disease model explains the same theoretical results as the rational addiction model and includes results that more accurately describe the behavior of new smokers even though it includes a myopic economic model of consumption. Empirical results of the rational addiction model, however, seem to reject a myopic model of consumption. We use a simulation model to test whether the consumption patterns of individuals that follow the behavior of the infectious disease model could generate, qualitatively, the same results as those found in the empirical studies of the rational addiction model.

To test for this match of empirical and simulated results, we used the infectious disease model to simulate a data set of addictive consumption. Because the data set was simulated using the infectious disease model, the data were myopic by definition. We then estimated the demand equation from the rational addiction model using the simulated data set and the same estimation techniques used in previous studies of the rational addiction model (Becker, et al., 1994; Chaloupka, 1991). The results of our analysis demonstrate that the empirical results found previously using the rational addiction model are necessary, but not sufficient conditions for the existence of forward looking behavior.

A. Individual Behavior

The simulation of the infectious disease model uses the grid of consumers shown in Figure 2. Each cell represents one consumer, and each individual who consumes the addictive good follows the demand curve in (5). Individuals who do not consume the addictive good accumulate probability of becoming smokers from those around them during each time period. For example, if individual A in Figure 2 does not consume the addictive good, then A's probability of consuming it in period t is determined by the consumption status of A's parents or other adult role models ("B" cells), A's friends ("C" cells) and the total prevalence in society according to Equation (7) in which X_j represents the average prevalence of use of the addictive good in group j . Thus if one of the individual's "parents" becomes addicted, the individual's own probability of becoming addicted increases. Each individual's probability of becoming a smoker is initially set to 0. The probability of becoming a smoker is treated cumulatively with a depreciation rate on the previous periods probability of κ , thus the probability for individual i to become a smoker in period t depends upon their probability of becoming a smoker in period $t-1$ as in Equation (7). Treating the probability of becoming a smoker as a cumulative function assumes that societal effects are not instantaneous, but rather a process that takes time to take hold on the individual's behavior.

$$\varphi_{i,t} = \lambda_{\text{parents}} X_{\text{parents},t} + \lambda_{\text{friends}} X_{\text{friends}(i),t} + \lambda_{\text{society}} X_{\text{society}(i),t} + \kappa_i \varphi_{i,t-1} \quad (7)$$

For the simulation, $\lambda_{\text{parents}} = 0.5$, $\lambda_{\text{friends}} = 0.4$ and $\lambda_{\text{society}} = 0.1$, with various combinations of other parameter values used for confidence testing and $\kappa_i \sim U[0.5, 1]$.⁷

After determining the individual's probability of becoming a smoker, a random draw of $r_{i,t} \sim U[0, 1]$ is used to determine whether $I_{i,t}(\phi_{i,t}, r_{i,t})$ is equal to 1 or 0 according to (2). Once $I_{i,t}$ is equal to 1, the individual follows the demand for the addictive good in (5).

⁷More sophisticated learning models could be used in place of this simple linear cumulative probability function. The model of probabilistic infection is used to keep the model as simple as possible.

Each individual draws the parameter values from the following distributions⁸:

$$\begin{aligned}\beta &\sim U[0, 40] \\ \omega &\sim U[0, 80] \\ \alpha &\sim U[0, 1] \\ \gamma &\sim U[0, 0.25] \\ \theta &\sim U[0, 0.25]\end{aligned}$$

It was necessary to focus the analysis on one distribution for each of the parameter values, to ensure that all results were driven purely by price changes. The particular distributions were used because they provided nonzero prevalence rates that were less than 1. Additionally, assuming an initial smoking prevalence of 25%⁹ and a price range of 1 to 10, these distributions imply short run money price elasticities according to equation (6a) of -0.44 to -0.89, which are consistent with previous estimates of the money price elasticity of cigarettes by the rational addiction model (Chaloupka, 1991). The distributions of the parameters are not unique and a sensitivity analysis of these parameters is in the Appendix.

Two additional constraints were placed on individuals. First, individuals were assumed to live for 100 time periods after which they were “reborn” with the same parameter values, but probability of becoming a smoker set equal to 0. Second, in order to more closely mimic the behavior of smokers, it is assumed that individuals collect probability from birth, but cannot become a smoker before time period 12 or after 25 (so each time period is assumed to be 1 year).

B. The Simulation Environment

The grid used was a 121×121 square with 14,641 cells. This large population of cells provides an appropriate level of variation of parameter sets among the cells of the grid so that the results are not dependent upon the location of the cells and their randomly drawn parameter values. The cells on the border of the grid were matched so that each individual had three “parents”¹⁰ and five “friends.” For example, cells on the far right edge of the grid had one “parent” and two “friends” on the far left border. This matching of the cells from each border of the grid creates a tetrahedron so that the space is continuous and all cells have a uniform number of parents and friends. Initial ages of the individuals were distributed according to U[0,100].

C. The Simulation Algorithm¹¹

The focus of the simulation is to generate price and consumption data similar to that used in the empirical studies of the rational addiction model. Since the infectious disease model describes only the demand side, the price data must be generated. Price was treated as an exogenous variable and was varied over time (Figures 3a-3e). The price paths were set so that the effects of price trends and onetime price changes could be detected over time. Both increasing and decreasing price patterns were used in each price path, as well as several periods of constant price following single price increases and decreases. The simulated price paths provide large data sets that allow for the testing of multiple types of behavior within the model that using actual the limited data of actual price paths would not allow. Different

⁸Normal distributions were also used with no material difference in results.

⁹A range of initial prevalence rates were tested with no effect on the results of the simulation.

¹⁰The “parents” may also represent other adult role models.

¹¹The simulation was implemented in NetLogo 1.2. The working model and code is available as an additional file linked with this paper.

price paths were used in each experiment. Each price path used had a different level of variation as well as different maximum and minimum levels in an effort to ensure that the statistical results shown in the next section were not biased by the price paths and were not dependent on any particular price path.

The infectious disease model incorporates the social price of smoking. While the social price is important to the overall analysis of addictive consumption, the empirical studies of the rational addiction model do not account or attempt to study the social price. In order to keep the simulation focused on money price and consumption, the social price will not be varied in the simulation.

Five experiments were run that differed in initial price and price path. The initial prices used were from the set {1,2,3,4,5} and the simulation followed the algorithm below.

- I. Initial parameter values, prevalence¹² and price set up
- II. 150 time periods elapsed to insure a steady state of consumption. In each period, all individuals updated their propensity to smoke and their consumption choice each time period.
- III. Price was varied over time for the next 1100 time steps

The prices paths used and the simulated consumption paths are shown in figures 3a-3e.

D. Results¹³

The data simulated by the myopic infectious disease model can now be used to estimate the demand equation from the rational addiction model. The data from the last 1100 time steps of the simulation experiments, using the infectious disease model were used to estimate the demand equation specified by the rational addiction model in (8). Several studies have examined addictive consumption using the rational addiction model. Equation (8) has been estimated with both aggregate (Becker, et al., 1994)¹⁴ and individual level cigarette consumption data (Chaloupka, 1991).

$$c_{i,t} = \beta_0 + \beta_1 P_{c,t} + \beta_2 P_{c,t-1} + \beta_3 P_{c,t+1} + \beta_4 c_{i,t-1} + \beta_5 c_{i,t+1} \quad (8)$$

Both empirical studies of the rational addiction model find a positive and significant correlation between $c_{i,t}$ and $c_{i,t+1}$ which they argue to be causation. Both Becker et al and Chaloupka argue that the positive correlation is causation which rejects myopic demand models of consumption and validates the rational addiction model. They both used least squares and two-stage least squares estimation with multiple sets of instruments, including lags and leads of prices and cigarette taxes as well as the explanatory variables of the model, in the two-stage least squares approaches. Table 3 summarizes a sampling of their empirical results which show the highly significant positive correlation between current and future consumption. The initial 150 time steps were not used in the data analysis to wash out the effects of the assumed initial conditions. Visually, Figures 3a-3e show that the simulated data exhibit the expected inverse relationship between price and quantity. We then applied the same regression techniques used by Chaloupka (Chaloupka, 1991) and Becker et al

¹²Initial prevalence was set to 25%. Since simulation is run forward 150 time steps until the analysis is begun, in order to wash out the effects of the initial conditions, no variation of the initial prevalence was done in these experiments. Other runs of the simulation that vary the initial prevalence show that the initial prevalence has no effect on the eventual steady state of the model.

¹³A similar analysis was done on individual level data as done in Chaloupka (Chaloupka, 1991). The data from this analysis exhibited the same correlation between current and future consumption as the aggregate data does.

¹⁴As noted above Becker et al do not use future and past prices in their regressions.

(Becker, et al., 1994) to these simulated data. The results of the regression using least squares and following the demand equation used by Chaloupka and the simulated data are shown in Table 4a and the two stage least squares results using the demand equations in Becker et al and the simulated data are in Table 4b. The last column of Table 4a and Table 4b indicate the sign for each estimate found by the empirical studies using the rational addiction model (Becker, et al., 1994; Chaloupka, 1991). The sign of each estimate from the simulated data matches the sign of the estimates from the empirical rational addiction studies.

The results from the analysis of the simulated data from the infectious disease model (Tables 4a-b) qualitatively match those of the empirical results found for cigarette consumption. Since the individuals in the simulated model are undeniably myopic, the positive correlation found between current and future consumption in all of the experiments demonstrates that this correlation does not require a forward looking and rational consumer as Chaloupka and Becker et al argue. Our simulation shows that the positive correlation is simply further validation of the addictive properties of the good. If an individual is addicted to a good there will be a positive correlation between current and future consumption for the individual, just as there is a correlation between past and present consumption. This correlation does not require or imply a forward looking rational choice by consumers.

The simulated data used in this analysis were generated using a purely myopic model, yet the rational addiction model provided a good fit. The matching results from the simulated myopic infectious disease model and the empirical analysis of the rational addiction framework demonstrates that the estimated correlation between current and future consumption is a necessary, but not sufficient condition to prove the existence of forward looking behavior in addicts. All the theoretical and empirical results of the rational addiction model can be fully explained by a myopic infectious disease model.

VI. Conclusion

The initial consumption of addictive goods has not been previously modeled as an infectious disease. Previous models rely on heavy discount rates (Orphanides and Zervos, 1998; Suranovic, et al., 1999) or imperfect information (Orphanides and Zervos, 1995) to explain initial consumption. These models create logical and empirical inconsistencies. The infectious disease model, however, allows an individual's behavior with regard to addictive goods to be conditioned on their environment, which is more consistent with the empirical evidence on initiation of smoking.

The infectious disease model also adds a social effect to consuming an addictive good which can be used as a policy variable. While individuals may perceive the social effect of smoking differently, the social effect can be raised, and consumption reduced, by smokefree ordinances and media campaigns that portray the use of addictive goods as antisocial. For example, smoking prevalence has declined much faster in US in wealthier populations, the infectious disease model suggests that smoking is thought of more as antisocial behavior by wealthier populations and any attempt to further reduce smoking among lower socioeconomic groups needs to foster the idea that smoking is antisocial. Both of these policies have been implemented and shown to be effective in reducing the consumption of cigarettes (Bitton, et al., 2001; Fichtenberg and Glantz, 2002).

The simulation of the infectious disease model created a data set driven by purely myopic behavior. Using the same analysis as in the empirical work on rational addiction (Becker, et al., 1994; Chaloupka, 1991) we found that myopic behavior can generate the same results in the rational addiction framework as the results previously used to argue for the presence of

forward looking behavior. This analysis of a myopic data set shows that the empirical results of the rational addiction model are a necessary but not a sufficient condition to prove the existence of forward looking behavior. Myopic models, such as the infectious disease model proposed here, are therefore viable alternatives to the rational addiction model in analyzing addictive consumption.

Appendix

The results of ten additional simulation runs are summarized in Table A1. The distributions for the parameter values vary by simulation run and are shown in Table A2. These additional simulation runs further confirm the results shown in the above in tables 3a and 3b.

Table A1
Sensitivity Analysis of Simulated Consumption Using Least Squares Estimates of Rational Addiction Demand Equations (Chaloupka)

Independent Variable	Experiment									
	1	2	3	4	5	6	7	8	9	10
Price($t-1$)	2.16 (10.57)	3.11 (10.54)	2.17 (10.09)	2.68 (7.72)	4.11 (10.14)	2.77 (12.14)	3.47 (9.36)	6.91 (13.12)	5.39 (10.68)	4.74 (9.62)
Price(t)	-5.22 (-13.15)	-8.05 (-17.87)	-9.76 (-15.51)	-6.14 (-17.12)	-7.52 (-20.27)	-6.31 (-18.47)	-6.12 (-25.82)	-9.41 (-24.17)	-12.84 (-19.91)	-9.64 (-13.78)
Price($t+1$)	3.22 (9.67)	4.15 (12.36)	3.78 (11.57)	3.67 (9.61)	3.57 (10.93)	4.05 (10.47)	4.81 (12.56)	7.21 (18.17)	6.41 (11.98)	5.21 (10.31)
Lagged Consumption	0.49 (30.11)	0.49 (41.21)	0.49 (46.01)	0.48 (36.11)	0.49 (27.39)	0.50 (35.62)	0.48 (21.07)	0.49 (39.38)	0.49 (33.18)	0.49 (25.14)
Future Consumption	0.51 (31.24)	0.51 (40.75)	0.51 (46.23)	0.49 (33.87)	0.49 (33.94)	0.48 (28.17)	0.5 (23.17)	0.5 (39.35)	0.49 (36.33)	0.49 (25.31)

Note: Asymptotic t-ratios are shown in parentheses. All estimates were statistically significant to the 5 percent level in all experiments except for the Intercept term which was not found to be significant in any of the experiments.

Table A2

Distributions of Parameter Values for Sensitivity Analysis

Parameter	Simulation									
	1	2	3	4	5	6	7	8	9	10
Beta	U[10, 40]	U[30, 60]	U[50, 100]	U[25, 75]	U[0, 100]	U[70, 80]	U[0, 100]	U[0, 100]	U[0, 100]	U[0, 50]
Theta	U[0.1, 0.6]	U[0, 1]	U[0, 2]	U[0, 5]	U[4, 5]	U[2.5, 3.5]	U[5, 10]	U[5, 10]	U[5, 10]	U[2, 7]
Omega	U[20, 70]	U[5, 105]	U[0, 200]	U[5, 25]	U[0, 10]	U[10, 20]	U[0, 300]	U[0, 300]	U[0, 300]	U[0, 50]
Gamma	U[0.1, 0.6]	U[0, 1]	U[0.25, 1]	U[1, 3]	U[0, 2]	U[0.5, 1.5]	U[0, 3]	U[0, 3]	U[0, 3]	U[0, 2]
Alpha	U[1.1, 2.1]	U[0, 5]	U[5, 10]	U[0, 1]	U[0, 0.5]	U[0, 0.5]	U[0, 1]	U[0, 1]	U[0, 1]	U[0, 2]
Parental Influence	0.4	0.4	0.34	0	0.6	0.45	0.8	0.05	0	0.5
Friends Influence	0.35	0.3	0.33	0	0.2	0.45	0.1	0.5	0.75	0.45
Society Influence	0.25	0.3	0.33	1	0.2	0.1	0.1	0.45	0.25	0.05
Initial Price	4	3	2	6	5	6	5	5	5	5
Initial Prevalence	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

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Figure 1. Consumption of the Addictive Good As a Function of Past Consumption

	B	B	B
C	A	C	
C	C	C	

Figure 2. Simulation Grid

Figure 3.

Figure 3a. Price and Consumption Per Capita: Experiment #1

Figure 3b. Price and Consumption Per Capita: Experiment #2

Figure 3c. Price and Consumption Per Capita: Experiment #3

Figure 3d. Price and Consumption Per Capita: Experiment #4

Figure 3e. Price and Consumption Per Capita: Experiment #5

Table 1
Environmental Predictors of Smoking Initiation in 27 Prospective Studies

Environmental Predictor	Number of Supportive Findings	Number of Unsupportive Findings	Percent Support
Family Smoking	18	8	69%
Family Approval	6	8	43%
Other Adult Influences	5	3	63%
Peer Use and Approval	27	5	84%
Normative Estimates	4	1	80%
Offers/Availability	7	1	88%
Family Bonding	9	6	60%
Peer Bonding	11	4	73%
School Influences	20	5	80%
Religious Influences	0	1	0%

Source: (US Department of Health and Human Services, 1994)

Table 2
Comparing the Assumptions and Explained Behavior of the Infectious Disease and Rational Addiction Models

	Rational Addiction	Infectious Disease
Assumptions		
Infectious Initial Consumption	No	Yes
Social Price	With Modification	Yes
Concave Utility	Yes	Yes
Multiple Period Budget Constraint	Yes	No
Single Period Budget Constraint	No	Yes
Maximization Over Multiple Periods	Yes	No
Behavior		
Initiation *	No	Yes
Rapid, short term, increase in consumption (binging)	Yes	Yes
Drop in consumption to 0 in one time period (Cold Turkey)	Yes	Yes
Price Effects	Yes	Yes
Social Effects for Nonsmokers	No	Yes
Social Effects for Smokers	With Modification	Yes

* Extensions to the rational addiction model with incomplete information have attempted to model initiation (Orphanides and Zervos, 1995). These attempts have lead to logical inconsistencies with empirical data (US Department of Health and Human Services, 1994).

Table 3
Empirical Results of the Rational Addiction Model on Consumption

Independent Variable	Becker et al	Chaloupka
Price(t-1)	-	6.856
	-	(1.11)
Price(t)	-1.388	-12.576
	(8.94)	(-1.76)
Price(t+1)	-	4.095
	-	(1.01)
Lagged Consumption	0.418	0.516
	(8.88)	(3.32)
Future Consumption	0.135	0.268
	(2.45)	(1.19)

Note: Asymptotic t-ratios are shown in parentheses. The critical asymptotic t-ratios are 1.64 for a one-tailed test and 1.96 for a two-tailed test at the 5 percent level.

Table 4

Table 4a. Simulation Results, Least Squares Estimates of Consumption Using Rational Addiction Demand Equations (Chaloupka)

Independent Variable	Experiment				
	1	2	3	4	5
Price(t-1)	18.78 (10.34)	12.39 (10.67)	40.57 (26.22)	8.07 (18.41)	1.97 (8.03)
Price(t)	-51.69 (-40.26)	-31.14 (-15.26)	-81.55 (-59.61)	-16.98 (-33.14)	-6.02 (-27.55)
Price(t+1)	33.62 (27.77)	19.91 (15.36)	41.01 (29.63)	9.31 (24.12)	4.14 (23.31)
Lagged Consumption	0.49 (37.14)	0.49 (24.31)	0.50 (33.04)	0.49 (39.31)	0.48 (38.17)
Future Consumption	0.50 (42.13)	0.51 (26.78)	0.50 (35.74)	0.51 (41.24)	0.50 (41.74)

Note: Asymptotic t-ratios are shown in parentheses. All estimates were statistically significant at the 5 percent level in all simulations.

Table 4b. Simulation Results, Two Stage Least Squares Estimates of Consumption Using the Rational Addiction Demand Equations (Becker et al)

Independent Variable	Experiment				
	1	2	3	4	5
Price(t)	-0.21 (-2.87)	-0.71 (-2.73)	-3.49 (-5.74)	-0.29 (-3.26)	-0.43 (-7.17)
Lagged Consumption	0.49 (43.81)	0.50 (33.14)	0.50 (33.74)	0.50 (38.67)	0.50 (46.37)
Future Consumption	0.51 (43.41)	0.49 (30.87)	0.48 (32.97)	0.50 (39.05)	0.49 (44.79)

Note: One period lagged price and one period future price, as well as the other explanatory variables in the model are used as instruments. Asymptotic t-ratios are shown in parentheses. All estimates were statistically significant at the 5 percent level in all simulations.