ABSTRACT

KOKSAL, AYCAN. Three Essays on the Interdependence between Cigarette and Alcohol Consumption. (Under the direction of Dr. Michael Wohlgenant.)

The three essays are presented to investigate the relation between cigarette and alcohol consumption employing household level data in a rational addiction framework. Household level data are a better tool to analyze the addictive behavior as aggregate data might conceal most of the individual behavior.

The first essay analyzes the relation between cigarette and alcohol consumption using two different household level data sets: Interview and Diary data (U.S. Bureau of Labor Statistics, Consumer Expenditure Survey). The different formats of the two data sets (i.e., rotating panel versus repeated cross-section) require the use of two different econometric methodologies in order to estimate the dynamic demand models. For the Interview data, within-groups two-step GMM method (Bover and Arellano, 1997) is used. For the Diary data, a pseudo-panel data approach is employed. The results obtained from the Diary data overall provide a better fit to the rational addiction model. It is argued that, for this particular study, the Diary data are more reliable than the Interview data, because the Interview data are likely to suffer from recall bias. Results based on the Diary data indicate that while cigarette and alcohol consumption reinforce each other, the long-run cross price elasticity of alcohol with respect to cigarette price is positive.

The second essay analyzes how smoking bans at restaurants affect restaurant alcohol consumption using Diary data and pseudo-panel approach. The main contribution of the paper is that, rather than analyzing how "overall alcohol consumption" is affected by smoking bans, the focus is on how "restaurant alcohol consumption" is affected by smoking

bans at restaurants. The empirical results point to an increase in restaurant alcohol consumption after a restaurant smoking ban is imposed.

In the third essay, the rational addiction model is generalized to include three addictive goods: cigarettes, alcohol and coffee. An important contribution of this paper is that by calculating Morishima elasticities of substitution, the substitutability of addictive goods along the indifference curve are explored. Long-run cross-price elasticities derived from the semi-reduced system and the Morishima elasticities of substitution reveal that when relative prices increase, consumers substitute addictive goods with other addictive goods.

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Three Essays on the Interdependence between Cigarette and Alcohol Consumption

by
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A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Economics

Raleigh, North Carolina

2012

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DEDICATION

To my family

BIOGRAPHY

Aycan Koksal was born in 1982 in Turkey. She is the daughter of Ilknur and Fazli Koksal and the older sister of Leman Handan Koksal. Aycan received her Bachelor of Arts degree in Economics with honors from Hacettepe University in 2005. She then moved to the United States, to pursue her graduate education in Economics. She received her Master's degree in Economics from North Carolina State University in 2007, and she is now completing her Ph.D. in Economics at North Carolina State University.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my advisor, Dr. Michael Wohlgenant, for his guidance, support and patience. I feel very lucky to have an advisor who believed in me and continuously encouraged me during this endeavor. I also would like to express my appreciation to Dr. Atsushi Inoue for his guidance on the econometric issues, and for devoting time to answer all my questions. I would like to thank my other committee members Dr. Nick Piggott and Dr. Xiaoyong Zheng for their valuable comments and suggestions.

I would like to acknowledge the emotional support I have received from many friends and colleagues during my studies. And finally, I thank to my family for their unconditional love, patience, encouragement and support.

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Introduction

One can argue that people who consume harmful addictive substances are likely to discount the future more compared to other people. Then, smokers should have present-oriented attitudes in general and are more likely to drink compared to other people. If cigarette consumption affects alcohol consumption (and vice versa), the information about their relationship may allow a better coordination of public policies concerning these two goods. In this dissertation, the relation between cigarette and alcohol consumption is investigated in a rational addiction framework through three essays. Previous studies that estimate cigarette and alcohol demands in the rational addiction framework used aggregate time series data. To analyze addictive behavior, household level data would be a better tool because aggregate data fail to give detailed information about individual behavior. Thus, household level data are used in all three essays in this dissertation.

The first essay investigates the relation between cigarette and alcohol consumption using two different data sets: Interview data and Diary data (U.S. Bureau of Labor Statistics, Consumer Expenditure Survey). The Interview data set is a rotating panel, while the Diary data set is a repeated cross-sectional survey. The different formats of the two data sets require the employment of different econometric methodologies to estimate dynamic demand models. For the Interview data within-groups two-step GMM method (Bover and Arellano, 1997) is used, while for the Diary data a pseudo-panel data approach is employed. The estimation results suggest that the Diary data overall are a better fit to the rational addiction model. It is argued that Interview data are likely to suffer from recall bias, and the results

obtained from Diary data are more reliable for this particular study. Diary data results indicate that cigarette (alcohol) consumption increases the marginal utility from alcohol (cigarette) consumption. On the other hand, long-run cross-price elasticities suggest alcohol is a substitute for cigarettes.

Using Diary data and pseudo-panel approach, the second essay investigates how smoking bans at restaurants affect restaurant alcohol consumption. In the past decade, many U.S. states have imposed smoking bans in a variety of locations. Particularly the smoking bans at restaurants create a natural experiment which allows us to get more insights on the relationship between cigarette and alcohol consumption. An important contribution of this paper is that, while the previous studies analyze how "overall alcohol consumption" is affected by smoking bans, this paper focuses on how "restaurant alcohol consumption" is affected by smoking bans at restaurants. The empirical evidence reveals that smoking bans increase restaurant alcohol consumption. On the other hand, it is found that reductions in the blood alcohol concentration limit for drivers would decrease both alcohol and cigarette consumptions.

The third essay analyzes the relationship between cigarette, alcohol and coffee consumption in a rational addiction framework using a pseudo-panel data approach. The objectives of this study are twofold: to gain more insight into behavioral processes concerning cigarette, alcohol and coffee consumption; and to generalize the rational addiction model to include three addictive goods. Another important contribution of the paper is that by calculating Morishima elasticities of substitution, the substitutability of different addictive goods along the indifference curve are revealed.

Chapter 1

Rational Addiction to Cigarette and Alcohol: Two Data Sets, Two Different Approaches

1.1. Introduction

The adverse health effects of smoking and drinking have long been recognized. There are also negative externalities associated with the consumption of cigarettes and alcohol (e.g., health consequences of passive smoking, injuries and fatalities resulting from drunk driving, the effects of alcohol on crime and labor performance). The public health care costs have made these two goods the prime targets of excise taxation in many countries.

With the harmful addictive substances, while the satisfaction from consumption is received now, damage to the health comes later. Then, it can be argued that people who consume harmful addictive substances are likely to discount the future more compared to other people. If smoking behavior is, in part, related to the attitudes toward time discounting, smokers should have present-oriented attitudes in general and are more likely to drink compared to other people. If cigarette consumption affects alcohol consumption (and vice

versa), the information about their relationship may allow a better coordination of the public policies concerning these two goods.

The rational addiction model (Becker and Murphy, 1988) is the most popular framework used to estimate the demand for addictive goods like cigarettes and alcohol. Becker and Murphy (1988) claim that addictions to harmful substances are still rational as the decision involves forward-looking maximization of utility. While myopic models of addictive behavior only accounts for *addiction*, Becker and Murphy's rational addiction model involves both *addiction* (i.e., an increase in past consumption increase current consumption), and *rationality* (i.e., consumer maximizes utility weighting current benefits and future costs). In myopic models, past consumption increases current consumption, but individuals do not take into account the future when making decisions on current consumption. In rational addiction model, the past and the anticipated future consumption both affect current consumption positively.

The rational addiction model has been previously applied to both cigarette consumption (e.g., Chaloupka, 1991; Becker et al., 1994; Jones and Labeaga, 2003) and alcohol consumption (e.g., Grossman et al., 1998; Waters and Sloan, 1995). Bask and Melkersson (2004) extended the rational addiction model to allow for multi-commodity addictions and estimated the demand for cigarettes and alcohol using aggregate time series data.

To analyze addictive behavior, household level data would be a better tool, as aggregate data might conceal most of the individual level behavior. Moreover, Auld and Grootendorst (2004) show that using aggregate data in the estimation tends to produce spurious evidence in

favor of the rational addiction. They indicate that most of the time time-series data are insufficient to differentiate rational addiction from serial correlation.

In this essay, two different household level data are employed to analyze the relation between cigarette and alcohol consumption in a rational addiction framework. Both data come from Consumer Expenditure Survey (CEX) by U.S. Bureau of Labor Statistics. The Consumer Expenditure Survey (CEX) consists of two separate data sets: a Diary survey and an Interview survey. Each survey uses its own questionnaire and its own sample. In the Interview data, each consumer unit is interviewed once every three months over five consecutive quarters. On the other hand, the sample changes every quarter in the Diary data. Due to the different formats of the two data sets, in order to estimate dynamic demand models, a different methodology is employed for each data set. Within-groups two-step GMM method (Bover and Arellano, 1997) is used for the Interview data. A pseudo-panel data approach is used for the Diary data.

Within-groups two-step GMM method not only deals with censoring, but also allows one to include lags and leads of the dependent variable, other endogenous explanatory variables, and unobserved individual fixed effects in the model. On the other hand, the pseudo-panel approach not only enables one to estimate dynamic demand models using cross-sectional data, but also avoids econometric difficulties due to measurement error, censoring and attrition bias.

The rest of this chapter is organized as follows. Section 1.2 gives a short literature review. Section 1.3 introduces the rational addiction model and the theoretical framework for two addictive consumption goods. Section 1.4 gives a discussion of the data set used. Section

1.5 and 1.6 explain the estimation methods used for the Interview and Diary data, respectively. Section 1.7 presents results. Section 1.8 has a discussion of the appropriate data and the methodology. Section 1.9 presents long-run demand elasticities derived from estimation with the Diary data. Section 1.10 concludes the study.

1.2. Literature Review

Although there is a vast amount of literature on estimating the demand for cigarettes and alcohol separately, there are only a few studies that investigate the interdependence between cigarette and alcohol consumptions. Among these studies only Bask and Melkersson (2004), Fanelli and Mazzocchi (2004) and Pierani and Tiezzi (2009) account for rationality in their specifications. However, all three studies use aggregate time series data in their analyses. Table 1.1 summarizes previous studies on the interaction between cigarette and alcohol consumption.

Goel and Morey (1995) analyze the interdependence between cigarette and liquor demand using a panel of U.S. state level data for the period 1959-1982. Cigarette and liquor demands are estimated separately and the interdependence between two goods is allowed through cross-price effects. The empirical specification accounts for addiction but not rationality. They find a substitution relationship with cross-price elasticities 0.10 and 0.33 for cigarettes and liquor, respectively.

Dee (1999) analyzes the relation between smoking and drinking using pooled cross-sectional data from the 1977-1992 Monitoring the Future (MTF) surveys of high school

seniors. Cigarette taxes and state minimum legal drinking ages are used to generate full prices of cigarette and alcohol. They find a complementarity relationship between cigarette and alcohol consumption. Elasticities are not calculated. The analysis is static.

Decker and Schwartz (2000) estimate separate static demand equations for cigarettes and alcohol using pooled cross-sectional data from the Behavioral Risk Factor Surveillance System (BRFSS). The interdependence between two goods is allowed through cross-price effects. Their model separates participation from consumption. They find that the cross price elasticity of cigarettes with respect to alcohol price is -0.14, while the cross price elasticity of alcohol with respect to cigarette price is 0.50.

Fanelli and Mazzocchi (2004) analyze the interdependence between tobacco and alcohol demand in UK using aggregate data over the 1963-2003 period. They develop a dynamic Almost Ideal Demand System (AIDS) model which is consistent with the rational addiction theory. They find a complementarity relation between tobacco and alcohol consumption with cross-price elasticities -0.50 and -1.16 for tobacco and alcohol, respectively.

Bask and Melkersson (2004) extend the rational addiction model to include two addictive goods, alcohol and cigarette. They use aggregate annual time series data from Sweden for the period 1955-1999. The sign of the estimated coefficients on lag and lead consumption are consistent with rational addiction theory in alcohol demand equation while it is not the case in cigarette demand equation. Cross-price elasticities are -0.31 and 0.79 for alcohol and cigarettes, respectively.

Tauchmann et. al (2006) analyze the relation between tobacco and alcohol consumption using German survey data collected in 1980, 1986, 1990, and 1992. Due to insufficient price

variation in the data, the demand equations are modeled such that latent consumption depends on the latent consumption of the other related good. They find a complementarity relationship between tobacco and alcohol consumption.

Pierani and Tiezzi (2009) employ a rational addiction model to analyze the interdependence between alcohol and tobacco consumption using aggregate annual time series data for the period 1960-2002 in Italy. Cross price elasticities are -0.24 and -1.15 for alcohol and tobacco, respectively.

Yu and Abler (2010) analyze the relation between cigarette and alcohol consumption in rural China, using a panel of provincial data for the period 1994–2003. They find that the cross-price elasticity of cigarette is -0.62, while the cross price elasticity of alcohol is 0.05.

1.3. Rational Addiction Model

Studies on addictions to harmful substances provide evidence of reinforcement effect. Reinforcement happens when an increase in past consumption increases the marginal utility from current consumption. Since rational consumers consider future negative consequences of harmful behavior, for an increase in consumption to occur the reinforcement effect should be larger.

Following Bask and Melkersson (2004), assume that

$$U_{it} = U(C_{it}, A_{it}, S_{it}, D_{it}, N_{it}) \quad (1.1)$$

where $C_{it}$and A_{it} are quantities of cigarettes and alcohol consumed by consumer i at period t; $S_{it}$and D_{it} are the habit stocks of cigarettes and alcohol; and N_{it} is the consumption of a non-addictive composite good.

The utility function is strictly concave. The marginal utility derived from each good is positive (i.e., $U_C > 0$, $U_A > 0$, and $U_N > 0$; concavity implies $U_{CC} < 0$, $U_{AA} < 0$, and $U_{NN} < 0$). Habit stocks of harmful substances affect current utility negatively due to their adverse health effects (i.e., $U_S < 0$ and $U_D < 0$; concavity implies $U_{SS} < 0$ and $U_{DD} < 0$).

Reinforcement means $U_{CS} > 0$ and $U_{AD} > 0$. Smoking and drinking are assumed to have no effect on the marginal utility derived from the composite good (i.e., $U_{NC} = U_{NA} = U_{NS} = U_{ND} = 0$). If consumption of alcohol (cigarettes) affects the marginal utility derived from cigarettes (alcohol) negatively, $U_{CA} < 0$ and $U_{SD} < 0$. If consumption of alcohol (cigarettes) reinforces the marginal utility derived from cigarettes (alcohol), $U_{CA} > 0$ and $U_{SD} > 0$.

If past alcohol consumption reinforces current cigarette consumption, $U_{CD} > 0$; if past cigarette consumption reinforces current alcohol consumption, $U_{AS} > 0$. Pierani and Tiezzi (2009) call this intertemporal cross-reinforcement effect a quasi-gateway effect. A true gateway effect refers to the condition where consumption of one addictive substance leads to later *initiation* of another addictive substance (Pacula, 1997). When alcohol consumption does not affect the marginal utility from cigarette consumption and vice versa, $U_{CA} = U_{SD} = U_{SA} = U_{CD} = 0$.

The intertemporal budget constraint is

$$\sum_{t=1}^{\infty} \beta^{t-1} \left(P_{Ct} C_{it} + P_{At} A_{it} + N_{it} \right) = W_i \tag{1.2}$$

where $\beta = 1/(1+r)$ with r being the discount rate, P_{Ct} and P_{At} are prices of cigarettes and alcohol, and W_i is the present value of wealth. As in previous studies, the discount rate is set equal to the interest rate. The composite good, *N*, is taken as numeraire, so that P_{Ct}, P_{At}, and W_i are expressed relative to the price of the composite good.

The consumer's problem is:

$$\max \quad \sum_{t=1}^{\infty} \beta^{t-1} U \left(C_{it}, A_{it}, S_{it}, D_{it}, N_{it} \right) \tag{1.3}$$

$$s.t. \quad \sum_{t=1}^{\infty} \beta^{t-1} \left(P_{Ct} C_{it} + P_{At} A_{it} + N_{it} \right) = W_i$$

Following previous studies, it is assumed that $S_{it} = C_{it-1}$ and $D_{it} = A_{it-1}$. When the utility function is quadratic, the first-order conditions from (1.3) generate the following structural equations for cigarettes and alcohol respectively (see Bask and Melkersson, 2003) :

$$C_{it} = \alpha_{1i} + \beta_{10} + \beta_{11} C_{it-1} + \beta_{12} C_{it+1} + \beta_{13} A_{it-1} + \beta_{14} A_{it} + \beta_{15} A_{it+1} + \beta_{16} P_{Ct} + \gamma_1 X_{it} + u_{1it} \tag{1.4}$$

$$A_{it} = \alpha_{2i} + \beta_{20} + \beta_{21} A_{it-1} + \beta_{22} A_{it+1} + \beta_{23} C_{it-1} + \beta_{24} C_{it} + \beta_{25} C_{it+1} + \beta_{26} P_{At} + \gamma_2 X_{it} + u_{2it} \tag{1.5}$$

where α_i is the individual fixed effect that accounts for unobserved individual heterogeneity. X_{it} includes real income and some consumer demographics.

Economic theory implies $\beta_{k6} < 0$ with k =1, 2. Rational addiction implies $\beta_{k1} > \beta_{k2} > 0$ with $\beta_{k1} = (1 + r)\beta_{k2}$.[1]

If $\beta_{14} > 0$ and $\beta_{24} > 0$ then alcohol (cigarette) consumption increases the marginal utility from cigarette (alcohol) consumption; and if $\beta_{14} < 0$ and $\beta_{24} < 0$ then alcohol (cigarette) consumption decreases the marginal utility from cigarette (alcohol) consumption. If $\beta_{13} > 0$, past alcohol consumption increases the marginal utility from current cigarette consumption; if $\beta_{23} > 0$, past cigarette consumption increases the marginal utility from current alcohol consumption. If there are no quasi-gateway effects across the two goods, $\beta_{13} = \beta_{15} = \beta_{23} = \beta_{25} = 0$.

1.4. Data

The main data source is the 2002-2008 Consumer Expenditure Survey (CEX) which is conducted by U.S. Bureau of Labor Statistics (BLS). U.S. Census Bureau collects the data for the BLS. BLS use CEX primarily to revise the market basket for the Consumer Price Index (CPI). In the academic literature, CEX data have been used to study many different issues from life-cycle hypothesis to consumer demand (e.g., De Juan and Seater, 1999; Puller and Greening, 1999; Nicol, 2003; Villaverde and Krueger, 2007). The CEX consists of a

[1]See Appendix A for explicit expressions for the parameters.

Diary survey and an Interview survey. Both surveys are conducted at the level of consumer units (CUs)[2], but each survey uses its own questionnaire and its own sample.

1.4.1. Consumer Expenditure Survey (CEX): Interview Component

The Interview component of CEX is a rotating panel. Each household is interviewed every three months over five consecutive quarters. In each quarter, 20 percent of the sample that finished their final interview in the previous quarter is replaced by CUs that are newly initiated. The survey is designed to constitute a representative sample of the U.S. population. Approximately 5,000 households are interviewed in each quarter.

The first interview collects data on the demographic characteristics, which is updated at subsequent interviews. The second through the fifth interviews collect expenditure information from the previous three months. Because the first interview is not reported by BLS, we use the second through the fifth interviews. From now on, the second interview is referred as the first interview, the third interview is referred as the second interview, and so on.

Cigarette, and alcohol expenditures, together with price variables, are used to calculate quarterly consumptions (i.e., cigarette consumption= cigarette expenditure/ cigarette price). The list and definitions of consumer demographics used are given in Table 1.2.

[2] A consumer unit comprises either: (1) all members of a particular household who are related by blood, marriage, adoption, or other legal arrangements; (2) a person living alone or sharing a household with others or living as a roomer in a private home or lodging house or in permanent living quarters in a hotel or motel, but who is financially independent; or (3) two or more persons living together who use their income to make joint expenditure decisions (http://www.bls.gov/cex/csxgloss.htm).

Because CUs are observed only for four quarters, the types of approximating models that can be used are limited. To estimate Equations (1.4) and (1.5), there must be at least four consecutive time period consumption data points for each CU in the survey. The Interview data meets this requirement. Because we need to have the consumption information of each household over at least four consecutive periods, we restrict our sample to CUs with complete interviews for four time periods. Because state information is used to match CUs with state level cigarette prices, we also drop the observations with missing state variables. The very few CUs who report different demographics (i.e., race, etc) over the four quarters that the expenditures are reported are also dropped.

1.4.2. Consumer Expenditure Survey (CEX): Diary Component

In the Diary data, the sample changes each quarter. The survey is designed to be a representative sample of the U.S. population. The data contain information on CU demographic characteristics and expenditures. The expenditures in the Diary data are collected from CUs for two consecutive one-week periods. Compared to Interview data, the Diary data supplies more information regarding subcategories of alcoholic beverage expenditures.

Cigarette and alcohol expenditures, together with price variables, are used to calculate (average weekly) consumptions (i.e., cigarette consumption= cigarette expenditure/ cigarette price). Because state information is used to match CUs with state level cigarette prices, the observations with missing state variables are dropped. The very few CUs who report

different demographics (i.e., race, etc) over the two weeks that the expenditures are reported are also dropped.

1.4.3. Price Variables

Since price data are not collected by CEX, price variables used in the analysis are gathered from other data sources. All price variables are deflated by the Consumer Price Index (CPI) for all items reported on the BLS webpage.

Annual state level cigarette prices are gathered from the State Tobacco Activities Tracking and Evaluation (STATE) System on the website of Department of Health and Human Services, Centers for Disease Control and Prevention (CDC). Prices are weighted averages for a pack of 20 cigarettes. Prices are inclusive of state-level cigarette excise taxes but are exclusive of local cigarette taxes. We merge CEX data and price data by state id variables.

We don't have state level or household level prices available for alcoholic beverages. To obtain alcoholic beverages prices, we construct Lewbel (1989) price indices which enable us to have household specific price variation.[3] Lewbel price indices are calculated using expenditure shares of each CU for different subcategories of alcoholic beverages, i.e., beer at home, wine at restaurant, etc[4].

[3] Hoderlein and Mihaleva (2008) show that Lewbel price indices produce better empirical results compared to the results obtained using traditional aggregate price indices.
[4] See Appendix B for details.

1.5. Methodology for Interview Data: Within-groups two-step GMM by Bover and Arellano

For the individual level data, consumption variables could be subject to censoring due to abstentions and corner solutions. In that case, the actual consumption of cigarettes (C_{it}) and alcoholic beverages (A_{it}) would be replaced by latent variables, C_{it}^* and A_{it}^*, respectively, in the equations. By using latent variables, it would be possible to capture probability effects (see Labeaga, 1999, for the discussion of the issue in a case study for tobacco consumption). To link observed and latent consumption, we assume a tobit-type observability rule:

$$C_{it} = max(0, C_{it}^*) \qquad (1.6)$$

$$A_{it} = max(0, A_{it}^*)$$

We generalize equations (1.4) and (1.5):

$$C_{it}^* = \alpha_{1i} + \beta_{10} + \beta_{11} C_{it-1}^* + \beta_{12} C_{it+1}^* + \beta_{13} A_{it-1}^* + \beta_{14} A_{it}^* + \beta_{15} A_{it+1}^* + \beta_{16} P_{Ct} + \gamma_1 X_{it} + u_{1it} \qquad (1.7)$$

$$A_{it}^* = \alpha_{2i} + \beta_{20} + \beta_{21} A_{it-1}^* + \beta_{22} A_{it+1}^* + \beta_{23} C_{it-1}^* + \beta_{24} C_{it}^* + \beta_{25} C_{it+1}^* + \beta_{26} P_{At} + \gamma_2 X_{it} + u_{2it} \qquad (1.8)$$

$$i = 1, \dots, N \qquad t = 1, \dots T$$

where C_{it}^* and A_{it}^* are latent dependent variables that are not directly observed. T is small and N tends to infinity.[5]

[5] In our data set, T=4 (we observe each CU for 4 quarters).

To deal with censoring, dynamics, endogeneous explanatory variables and unobservable fixed effects, we use within-groups two-step GMM method suggested by Bover and Arellano (1997). Because fixed effects are potentially correlated with exogenous variables, we follow Chamberlain (1984) and, Bover and Arellano(1997) in assuming:

$$E(\alpha_{ki}/Z_{it}) = \eta_{k0} + \sum_{t=1}^{T} \eta_{kt}^{'} Z_{it} + \eta_{kr}^{'} R_{it} \qquad \text{k=1, 2} \tag{1.9}$$

where Z_{it} are all exogenous variables including the real price of cigarettes and alcoholic beverages. R_{it} contains non-linear terms and/or interactions in Z_{it}.

Following Jones and Labeaga(2003), we also assume:

$$E(C_{i1}^{*}) = \mu_1' z_i \text{ and } E(C_{iT}^{*}) = \mu_2' z_i \tag{1.10}$$

$$E(A_{i1}^{*}) = \theta_1' z_i \text{ and } E(A_{iT}^{*}) = \theta_2' z_i$$

where $z_i = [\,1, Z_{i1}^{'}, \ldots, Z_{iT}^{'}, R_{it}^{'}]'$.

Therefore the reduced-form of the model is given by;

$$C_i^{*} = \Pi_1 z_i + \varepsilon_{1i} \tag{1.11}$$

$$A_i^{*} = \Pi_2 z_i + \varepsilon_{2i}$$

Following Bover and Arellano (1997), at the first-stage, we estimate each of the 2xT cross section equations in (1.11) using the tobit model. At the second stage, we apply within-groups method to the model (i.e, equations 1.7 and 1.8) after replacing the latent variables by their predicted counterparts estimated from reduced-form coefficients. The within-groups two-step estimators ($\hat{\beta}_{kWG}$) for cigarettes and alcohol are:

$$\widehat{\beta}_{1WG} = \left[\sum_{i=1}^{N} \hat{V}_{1i}^{'} K' K \hat{V}_{1i}\right]^{-1} \left[\sum_{i=1}^{N} \hat{V}_{1i}^{'} K' K I_0 \widehat{\Pi}_1 \mathrm{z_i}\right] \tag{1.12}$$

$$\hat{\beta}_{2WG} = \left[\sum_{i=1}^{N} \hat{V}_{2i}^{'} K' K \hat{V}_{2i}\right]^{-1} \left[\sum_{i=1}^{N} \hat{V}_{2i}^{'} K' K I_0 \widehat{\Pi}_2 \mathrm{z_i}\right]$$

with $\hat{V}_{1i} = \left[\Phi(L_1)\hat{\Pi}_1 z_i \vdots \Phi(L_2)\hat{\Pi}_1 z_i \vdots \Phi(L_1)\hat{\Pi}_2 z_i \vdots \hat{\Pi}_2 z_i \vdots \Phi(L_2)\hat{\Pi}_2 z_i \vdots P_C \vdots X_i\right]$.

$\hat{V}_{2i} = \left[\Phi(L_1)\hat{\Pi}_2 z_i \vdots \Phi(L_2)\hat{\Pi}_2 z_i \vdots \Phi(L_1)\hat{\Pi}_1 z_i \vdots \hat{\Pi}_1 z_i \vdots \Phi(L_2)\hat{\Pi}_1 z_i \vdots P_A \vdots X_i\right]$.

$\Phi(L_1)$ is the lagged operator, $\Phi(L_2)$ is the lead operator, $I_0 = [0 \vdots I_{T-2} \vdots 0]$, K is the first-difference or within groups operator.

Because Interview data are a rotating panel, following the suggestion of Manuel Arellano, we estimate the first-stage coefficients separately for each group (i.e., a group corresponds to the set of CUs that report consumption over the same time period). In the first-stage, we include demographics, all period prices and interactions between real income and prices. Since we have only 4 time periods, at the second stage we calculate two-step within-groups estimator by applying ordinary least squares (OLS) on fitted first differences. Bootstrapped standard errors are calculated with 1000 replications.

The first-stage estimation of the model requires sufficient price variation over time (i.e., price variation over the four quarters in which consumption is reported by each CU). Thus, to add quarterly price variation to the annual cigarette prices, we employ Litterman's minimum sum of squared residuals (min SSR) method using state cigarette excise taxes as related series.[6] The information on cigarette state excise taxes is reported quarterly on the website of CDC.

[6] See Appendix C for details on Litterman's method for temporal disaggregation of time series data.

1.6. Methodology for Diary Data: Pseudo-panel Approach

Although individual level panel data have many advantages compared to aggregate data, they generally span short time periods, suffer from measurement error and are subject to attrition bias. In order to avoid these problems, Deaton (1985) suggested using pseudo-panel data approach as an alternative method for estimating individual behavior models.

In the literature, for estimating dynamic models of demand, the pseudo-panel method is a relatively new econometric method. It is an instrumental variables approach in which cohort dummies are used as instruments in the first-stage (i.e., the first stage predicted values are equivalent to cohort averages). The pseudo-panel approach enables one to follow cohorts of people through repeated cross-sectional surveys. Because repeated cross-sectional surveys are often over longer time-periods than true panels, with pseudo panel method models can be estimated over longer time periods. Moreover, averaging within cohorts removes individual-level measurement error (see Antman and McKenzie, 2007).

In pseudo-panel analysis, because cohorts are followed over time, they are constructed based on characteristics that are time invariant, such as geographic region or the birth year of the reference person. When we construct cohorts, we face a trade-off between the number of cohorts and the number of individuals within cohorts. If individuals are allocated into a large number of cohorts, there will be few observations in the cohorts which might cause biased estimators. On the other hand, if only a few cohorts are chosen to have a large number of observations per cohort, individuals within a cohort might be heterogeneous, which would

cause inefficiency. Thus, the challenge when we construct a pseudo-panel is finding a balance between the number of cohorts and the number of individuals within cohorts. The optimal choice would be the one that minimizes the heterogeneity within each cohort but maximizes the heterogeneity among them. In that case, pseudo-panel method results in consistent and efficient estimators.

In most of the applied pseudo-panel studies, the sample is divided into a small number of cohorts with a large number of observations in each (e.g., Browning et al., 1985; Blundell, Browning and Meghir 1994; Propper, Rees and Green 2001). Verbeek and Nijman (1992) showed that if cohorts contain at least 100 individuals and there is sufficient time variation in the cohort means, the bias due to measurement error would be small and can be ignored[7].

In the pseudo-panel approach, cohorts can be constructed based on a single characteristic (i.e., birth cohort) or multiple characteristics (i.e., birth and region; birth and education, birth and gender, etc). In this study, we form pseudo-panels based on household head's year of birth and the geographic region. Cohorts are defined by the interaction of three generations (born before 1950, born between 1950-1964, born in 1965 or later) and four geographic regions (northeast, midwest, south, west). For example, all household heads born before 1950 that reside in the northeast would form one cohort and all households born before 1950 that reside in the midwest would form another cohort. The resulting pseudo-panel consists of a total of 336 observations over 12 cohorts and 28 quarters. This allocation results in around 100 households per cohort.

[7] They also state that the cohort sizes may be smaller than 100 observations if the individuals grouped in each cohort are sufficiently homogeneous.

Because pseudo-panel approach is an instrumental variables (IV) method, standard IV conditions should be satisfied for identification (Verbeek and Vella, 2005). The time-invariant instruments should have correlation not only with the lagged and lead consumption variables but also with the exogenous variables in the model (i.e., sufficient cohort-specific variation should be present in the exogenous variables). When we construct our cohorts, we take into account standard instrumental variables (IV) conditions. To have (time-variant) correlation between the model variables and the time invariant instruments (i.e., cohort dummies), we construct our cohorts based on household head's year of birth and the geographic region. The three generations (born before 1950, born between 1950-1964, born in 1965 or later) are likely to have different consumption patterns which are subject to change over time as the generations age. Different generations are likely to differ also in terms of consumer demographics (e.g., preference for small versus large families) which can change as generations age (e.g., family size changes as children leave the house to start their own family). There are also differences across regions in terms of prices, consumer demographics, and consumption patterns which would change over time because of migration, local policy changes, etc.

Figure 1.1 shows cigarette consumption by birth cohorts over the sample period. The youngest birth cohort has an increasing cigarette consumption on average, while the average cigarette consumption of older cohorts are decreasing from 2002 to 2008. The oldest cohort (i.e., people born before 1950) has the lowest cigarette consumption. Their low (and decreasing) consumption can be attributed to age related health problems which force older consumers to cut back cigarette consumption. The highest cigarette consumption is observed

among the people born between 1950-1964, which slightly decreases over the sample period. The people born after 1964 have a lower cigarette consumption compared to people born in 1950-1964. This can be explained by the 1964 surgeon general's report on smoking. The 1964 surgeon general's report caused awareness about the health consequences of smoking and changed public attitudes towards smoking.

Figure 1.2 shows alcohol consumption by birth cohorts over the sample period. From 2002 to 2008, the average alcohol consumption slightly increases for all birth cohorts. The oldest birth cohort (i.e., born before 1950) has the lowest alcohol consumption on average.

Figure 1.3 and Figure 1.4 show average consumptions by region. The midwest has the highest cigarette consumption, while west has the lowest. Cigarette consumption decreases in the midwest and west, while it increases in the south and northeast. Over the sample period alcohol consumption slightly increases across all regions, and among all regions the south has the lowest alcohol consumption.

In section 1.3, we derived the structural equations of the following form:

$$C_{it} = \alpha_{1i} + \beta_{10} + \beta_{11} C_{it-1} + \beta_{12} C_{it+1} + \beta_{13} A_{it-1} + \beta_{14} A_{it} + \beta_{15} A_{it+1} + \beta_{16} P_{Ct} + \gamma_1 X_{it} + u_{1it} \quad (1.4)$$

$$A_{it} = \alpha_{2i} + \beta_{20} + \beta_{21} A_{it-1} + \beta_{22} A_{it+1} + \beta_{23} C_{it-1} + \beta_{24} C_{it} + \beta_{25} C_{it+1} + \beta_{26} P_{At} + \gamma_2 X_{it} + u_{2it} \quad (1.5)$$

In order the estimate the individual level structural equations (1.4) - (1.5), we use cohort dummies as instruments in the first-stage. Taking cohort averages of (1.4) - (1.5), over n_c individuals observed in cohort c at time t results in:

$$\bar{C}_{c(t),t} = \bar{\alpha}_{1c,t} + \beta_{10} + \beta_{11}\bar{C}_{c(t),t-1} + \beta_{12}\bar{C}_{c(t),t+1} + \beta_{13}\bar{A}_{c(t),t-1} + \beta_{14}\bar{A}_{c(t),t}$$
$$+\beta_{15}\bar{A}_{c(t),t+1} + \beta_{16}P_{Ct} + \gamma_1\bar{X}_{c(t),t} + \bar{u}_{1c(t),t} \quad (1.13)$$

$$\bar{A}_{c(t),t} = \bar{\alpha}_{2c,t} + \beta_{20} + \beta_{21}\bar{A}_{c(t),t-1} + \beta_{22}\bar{A}_{c(t),t+1} + \beta_{23}\bar{C}_{c(t),t-1} + \beta_{24}\bar{C}_{c(t),t}$$
$$+\beta_{25}\bar{C}_{c(t),t+1} + \beta_{26}P_{At} + \gamma_2\bar{X}_{c(t),t} + \bar{u}_{2c(t),t} \quad (1.14)$$

In repeated cross-sectional data, different individuals are observed at each time period. Thus, the lagged and lead variables are not observed for the same individuals in cohort c at time t. Therefore, following the previous literature, we replace these sample means of the unobserved variables with the sample means of the individuals at time t−1, and t+1, respectively, which leads to the following equations[8]:

$$\bar{C}_{c(t),t} = \bar{\alpha}_{1c,t} + \beta_{10} + \beta_{11}\bar{C}_{c(t-1),t-1} + \beta_{12}\bar{C}_{c(t+1),t+1} + \beta_{13}\bar{A}_{c(t-1),t-1} + \beta_{14}\bar{A}_{c(t),t}$$
$$+ \beta_{15}\bar{A}_{c(t+1),t+1} + \beta_{16}P_{Ct} + \gamma_1\bar{X}_{c(t),t} + \bar{u}_{1c(t),t} \quad (1.15)$$

$$\bar{A}_{c(t),t} = \bar{\alpha}_{2c,t} + \beta_{20} + \beta_{21}\bar{A}_{c(t-1),t-1} + \beta_{22}\bar{A}_{c(t+1),t+1} + \beta_{23}\bar{C}_{c(t-1),t-1} + \beta_{24}\bar{C}_{c(t),t}$$
$$+ \beta_{25}\bar{C}_{c(t+1),t+1} + \beta_{26}P_{At} + \gamma_2\bar{X}_{c(t),t} + \bar{u}_{2c(t),t} \quad (1.16)$$

where $\bar{\alpha}_{c,t}$ is the average of the fixed effects for those individuals in cohort *c* at time *t*.

Since the sample is collected separately at different time periods, $\bar{\alpha}_{c,t}$ is not constant over time. $\bar{\alpha}_{c,t}$ can be treated as unobserved cohort fixed effect (α_c) if there is sufficient number of observations per cohort (see Verbeek and Nijman, 1992). In that case, we can estimate the structural equations at the cohort level by using cohort dummies or cohort fixed effects. In the dynamic pseudo-panel data model, the fixed effects estimator on cohort averages is

[8] As the number of individuals in each cohort becomes large, the measurement error introduced by the use of pseudo-panel analysis, i.e.$\bar{C}_{c(t),t-1} - \bar{C}_{c(t-1),t-1}$ converges to zero (McKenzie,2004).

consistent when T is small and $n_c \to \infty$ provided that there are no cohort and time effects in the individual error terms once controlled by cohort fixed effects (McKenzie, 2004). The number of observations in each cohort is sufficiently large in our sample to ensure consistency. Thus the fixed effects estimator on cohort averages is calculated.

In the sample, the number of households in each cohort and time period is not the same which might induce heteroskedasticity. Following Dargay (2007), to correct for heteroskedasticity, all cohort variables are weighted by the square root of the number of households in each cohort. To obtain consistent standard errors, bootstrapped standard errors are calculated (1000 replications).

1.7. Empirical Results

Equations 1.4 and 1.5 are estimated separately with both data sets. The application of the within groups two-step GMM estimator to the Interview data set results in coefficient estimates that contradict with the rational addiction theory (see Table 1.3). In both cigarette and alcohol equations, we find negative coefficients on lag and lead consumption, which does not only contradict rationality but also is inconsistent with habit formation. The price coefficient is positive in the cigarette consumption equation, which is also inconsistent with economic theory. We drop out the CUs who do not report any cigarette or alcohol consumption and replicate the estimations. The coefficients on lag and lead consumption are still negative. To analyze this further, we employ simple two-stage least squares (2SLS) on first differenced equations (see Table 1.4). In the alcohol consumption equation the

coefficients on lag and lead coefficient are still negative. In the cigarette consumption equation, the coefficient on lag consumption is positive, and the coefficient on lead consumption is negative but none of the coefficients are statistically significant. The coefficient of determination is very low for both cigarette and alcohol equations when 2SLS method is employed (0.06 and 0.04 for cigarettes and alcohol equations, respectively). We drop out the CUs who do not report any cigarette or alcohol consumption and replicate the 2SLS estimation on first differenced equations, and there is no change in the signs of the model coefficients and there is no improvement on the coefficient of determination.

Although the coefficient estimates from 2SLS and within groups two-step GMM methods suggest positive reinforcement between cigarette and alcohol consumptions (i.e., in most specifications, the coefficient on current cigarette consumption in alcohol equation is positive and significant; the coefficient on current alcohol consumption in cigarette equation is positive and significant), one should be cautious in reaching any conclusions based on this analysis since the signs on lagged and lead consumption coefficients are not consistent with the rational addiction model. We also tried different set of demographics/instruments, but there was still no improvement on the estimates.

Table 1.5 reports the estimation results from using Diary data and pseudo-panel approach. Consistent with the economic theory, own price has a negative coefficient in both equations, but it is only significant in alcohol equation. Cigarette consumption is consistent with rational addiction (i.e., lag and lead consumption coefficients are positive), and the estimated discount rate is positive (i.e., the coefficient on lag consumption is higher than the coefficient on lead consumption). On the other hand, in the alcohol equation lag and lead

consumption coefficients are negative which might be due to inventory effects as we derive consumption from expenditures. In the alcohol equation, current cigarette consumption has a positive and significant coefficient which suggests cigarette consumption reinforces alcohol consumption. In the cigarette equation, current alcohol consumption has a positive coefficient which suggests alcohol consumption reinforces cigarette consumption. We have not found any support for quasi-gateway effect across cigarette and alcohol consumption. Lagged cigarette (alcohol) consumption in the alcohol (cigarette) equation is not statistically significant.

Regarding consumer demographics, it is found that as family size increases real expenditures of both cigarettes and alcohol increase. Our results suggest that whites smoke and drink more compared to other races. The consumer units whose household head has a college degree (i.e., associate's degree or higher) smoke less cigarettes, but drink more alcohol compared to other consumer units. The effect of education on consumption is not statistically significant. Cohort fixed effects are jointly significant in both equations (i.e., the F-test is at the 1% level where F-values are 7.07 and 3.58 in cigarette and alcohol equations, respectively).

1.8. Discussion

The results from the Diary data are overall more consistent with the rational addiction theory compared to the results from the Interview data.

In the Frequently Asked Questions, BLS explains the purpose of Diary and Interview Data:

> "*The two survey components—the Interview Survey and the Diary Survey—are designed to collect different types of expenditures. The Interview Survey is designed to obtain data on the types of expenditures respondents can recall for a period of 3 months or longer. These include relatively large expenditures, such as those for property, automobiles, and major durable goods, and those that occur on a regular basis, such as rent or utilities. Each consumer unit is interviewed once per quarter for five consecutive quarters. The Diary Survey is designed to obtain data on frequently purchased smaller items, including food and beverages, both at home and in food establishments, housekeeping supplies, tobacco, nonprescription drugs, and personal care products and services. Each consumer unit records its expenditures in a diary for two consecutive 1-week periods. Respondents are less likely to recall such purchases over longer periods. Although the diary was designed to collect information on expenditures that could not be easily recalled over time, respondents are asked to report all expenses (except overnight travel) that the consumer unit incurs during the survey week.*" (http://www.bls.gov/cex/csxfaqs.htm).

Given the design of the two data sets, it can be argued that expenditures on frequently purchased items such as cigarettes and alcohol are more accurately reported in the Diary data. In the Interview data, the accuracy and validity of these types of expenditures might

have been distorted because of the recall error. Recall error has two main forms: omission and telescoping. Omission means forgetting an event entirely. Telescoping, on the other hand, means remembering an event but displacing it in time (i.e., recalling an event as having occurred more recently or longer ago than it actually did). Telescoping occurs, when respondents incorrectly include/exclude an event in the queried time period.

Omission causes underreporting, while telescoping may cause under or over-reporting, so the effect of recall error on the estimates of the model is ambiguous. Memory lapses can also cause simplification and/or modification of answers in a socially desirable direction, which can bias results by suggesting false associations or failing to indicate true relations. It will be particularly problematic if the recall error is systematic (i.e., different type of people have different recall abilities). Gmel and Daeppen (2007) show that recalled alcohol consumption decrease with the length of the recall period (a recall of 7 days versus a recall of 1 day), and recall biases are higher and significant among sporadic drinkers compared to regular drinkers.

Because forgetting is unlikely in Diary data, we can conclude that, for the current study, Diary data have more validity than Interview data. The consistency of coefficient estimates with the economic theory is another criterion for choosing the right data and the corresponding econometric approach. The estimates found using Interview data do not only contradict with rationality but they also contradict with addictive behavior. On the other hand, the pseudo-panel approach estimates from the Diary data fit pretty well to the model, especially for cigarette consumption.

1.9. The Long-Run Elasticities Derived From Diary Data

The results from Diary data are encouraging since the cigarette consumption is consistent with rational addiction theory. To take this one step further, we combine equations (1.4) - (1.5) to obtain a semi-reduced system. As pointed out by Bask and Melkersson (2004), decisions regarding cigarette and alcohol consumption are likely to be determined simultaneously. Thus, although the equations (1.4) - (1.5) give useful information about cross marginal utilities, the true solution of the consumer's utility maximization problem is:

$$\bar{C}_{ct} = \alpha_{3c} + \beta_{30} + \beta_{31}\bar{C}_{ct-1} + \beta_{32}\bar{C}_{ct+1} + \beta_{33}\bar{A}_{ct-1} + \beta_{34}\bar{A}_{ct+1} + \beta_{35}P_{Ct} + \beta_{36}P_{At} + \gamma_{31}\bar{X}_{ct} + \bar{u}_{3ct} \quad (1.17)$$

$$\bar{A}_{ct} = \alpha_{4c} + \beta_{40} + \beta_{41}\bar{A}_{ct-1} + \beta_{42}\bar{A}_{c\,t+1} + \beta_{43}\bar{C}_{ct-1} + \beta_{44}\bar{C}_{ct+1} + \beta_{45}P_{At} + \beta_{46}P_{Ct} + \gamma_{41}\bar{X}_{ct} + \bar{u}_{4ct} \quad (1.18)$$

The system of demand equations are estimated using iterated seemingly unrelated regression (ITSUR). The results are shown in Table 1.7. The parameters in these equations are non-linear functions of the parameters in equations (1.4) - (1.5), thus we don't have prior expectations for their signs. Instead, following Bask and Melkersson (2004), we focus on the long-run demand elasticities. The long-run price and income elasticities calculated at the sample mean are shown in Table 1.8. As expected, long-run own price elasticities are negative for both goods. Long-run cigarette demand is inelastic while long-run alcohol demand is elastic. There are other studies that report elastic alcohol demand in the long-run (i.e., Bask and Melkersson, 2004). The elastic (long-run) alcohol demand suggests that most

alcoholic beverage drinkers are social drinkers. The income elasticity is positive and less than one for both cigarettes and alcohol. The cross-price elasticity of cigarette with respect to alcohol price is negative while the cross-price elasticity of alcohol with respect to cigarette price is positive, but only the cross-price elasticity of alcohol is statistically significant.

The results are pretty interesting because long-run price elasticities derived from the semi-reduced system suggest alcohol is a substitute for cigarette while the coefficients of the structural equations suggest that alcohol consumption reinforce cigarette consumption and vice versa. This finding suggests an interesting question: Can two goods be substitutes in prices while they reinforce each other in consumption?

Picone et al.(2004) claim that although alcohol and cigarettes can be complements in consumption for social drinkers, they are gross substitutes in price. They bring up two theoretical explanations for the positive cross-price effects: compensation effect, and income effect. As cigarette prices increase many smokers reduce their consumption or quit smoking. In that case, smokers substitute alcohol for cigarette as a source of pleasure which is the compensation effect. In addition, as cigarette expenditures decrease, alcohol consumption increases due to a positive income effect given that alcohol is a normal good. Decker and Schwartz (2000) come up with a somewhat similar explanation in an analysis of smoking and drinking participation.

We believe that while cigarettes and alcohol reinforce each other in consumption, they become substitutes when there are permanent changes to the relative prices. Rational addiction theory claims that addicts are rational in the sense that they are forward looking and they maximize utility weighting current pleasure with future health costs. Then it is

plausible to expect that in the face of permanent price increases, smokers would cut their cigarette consumption and reallocate their lifetime income between cigarettes and alcohol. Moreover, rising cigarette prices will give smokers an incentive to decrease consumption or even to quit given that smoking is associated with more serious health problems. As mentioned in Picone et al.(2004) and Decker&Schwartz (2000), people who quit smoking are likely to compensate for the induced stress by increasing alcohol consumption.

1.10. Concluding Remarks

We use Interview and Diary data by BLS, to analyze the relation between cigarette and alcohol consumption in a rational addiction framework. In the Interview data, each consumer unit reports expenditures for four consecutive quarters. In the Diary data, the sample changes every quarter. Due to the different format of the two data sets, for each data set we employ a different methodology to estimate dynamic demand models. We employ within-groups two-step GMM method suggested by Bover and Arellano (1997) for the Interview data. We employ a pseudo-panel data approach for the Diary data.

The results derived from the Interview data not only contradict rationality but also contradict addictive behavior. The results from the Diary data overall fit better to the rational addiction theory compared to the results from the Interview data.

Given the design of the data sets, the accuracy and validity of cigarettes and alcohol expenditures might have been distorted in the Interview data because of the recall error. As suggested by previous studies, recall error would be particularly problematic if different sub-

groups of people have different recall abilities. Because forgetting is unlikely in Diary data, it can be argued that, for the current study, Diary data have more validity than Interview data. Thus, we focus on the estimates from the Diary data.

In the results derived from Diary data, cigarette consumption is consistent with rational addiction whereas alcohol consumption is not (i.e., in the alcohol demand equation lag and lead consumptions have negative coefficients). If there are inventory effects, it might be the reason why we are getting negative coefficients on the lag and lead consumption in the alcohol demand. The separate demand equations suggest cigarettes and alcohol reinforce each other in consumption (i.e., marginal utility of cigarettes increase as alcohol consumption increases, and vice versa). The cross price elasticity of alcohol with respect to cigarette price which is derived from the semi-reduced system suggests that alcohol is a substitute for cigarettes. Our estimation results are consistent with Picone et al.(2004) who claim that alcohol and cigarettes are gross substitutes in price although they might complement each other for social drinkers.

Gardes and Starzec (2002) estimate dynamic tobacco and alcohol demands on Polish panel data using an instrumentation based on birth cohorts which is very similar to the pseudo-panel approach that we employ. They compare the pseudo-panel estimation results with the results based on traditional instrumentation methods (i.e., using lag and lead prices as instruments for lag and lead consumption) and find that the pseudo-panel estimates fit the model much better. In the current study, overall pseudo-panel results obtained from using Diary data are also very encouraging. While many applied studies of rational addiction fail to find realistic discount rates, in the current study, the discount rates estimated for cigarette

demand seem plausible. We believe that the pseudo-panel approach has many advantages, not only because it allows one to estimate dynamic models with cross-sectional data, but it also avoids econometric difficulties due to measurement error, censoring and attrition bias.

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Tables and Figures

Table 1.1. Previous Literature on the Interdependence Between Cigarette and Alcohol Consumption

Papers	Data	Model Specification	ε_{CA}	ε_{AC}
Goel and Morey (1995)	panel of U.S. state level data	myopic	0.10	0.33
Dee (1999)	pooled cross-sectional data	static	-	-
Decker and Schwartz (2000)	pooled cross-sectional data	static	-0.14	0.50
Fanelli and Mazzocchi (2004)	aggregate time series	rational addiction	-0.50	-1.16
Bask and Melkersson (2004)	aggregate time series	rational addiction	0.79	-0.31
Tauchman et al. (2005)	pooled cross-sectional data	static	-	-
Pierani and Tiezzi (2009)	aggregate time series	rational addiction	-1.15	-0.24
Yu and Abler (2010)	provincial level panel data	myopic	-0.62	0.05

Table 1.2. The List and the Definitions of Demographics

Variable	Variable Definitions
AGE	age of the reference person
WHITE	1 if the reference person is white
COLLEGE	1 if the reference person has a bachelor's or a higher degree
FAMILY SIZE	number of members in CU
NORTHEAST	1 if CU resides in Northeast Census region
MIDWEST	1 if CU resides in Midwest Census region
SOUTH	1 if CU resides in South Census region

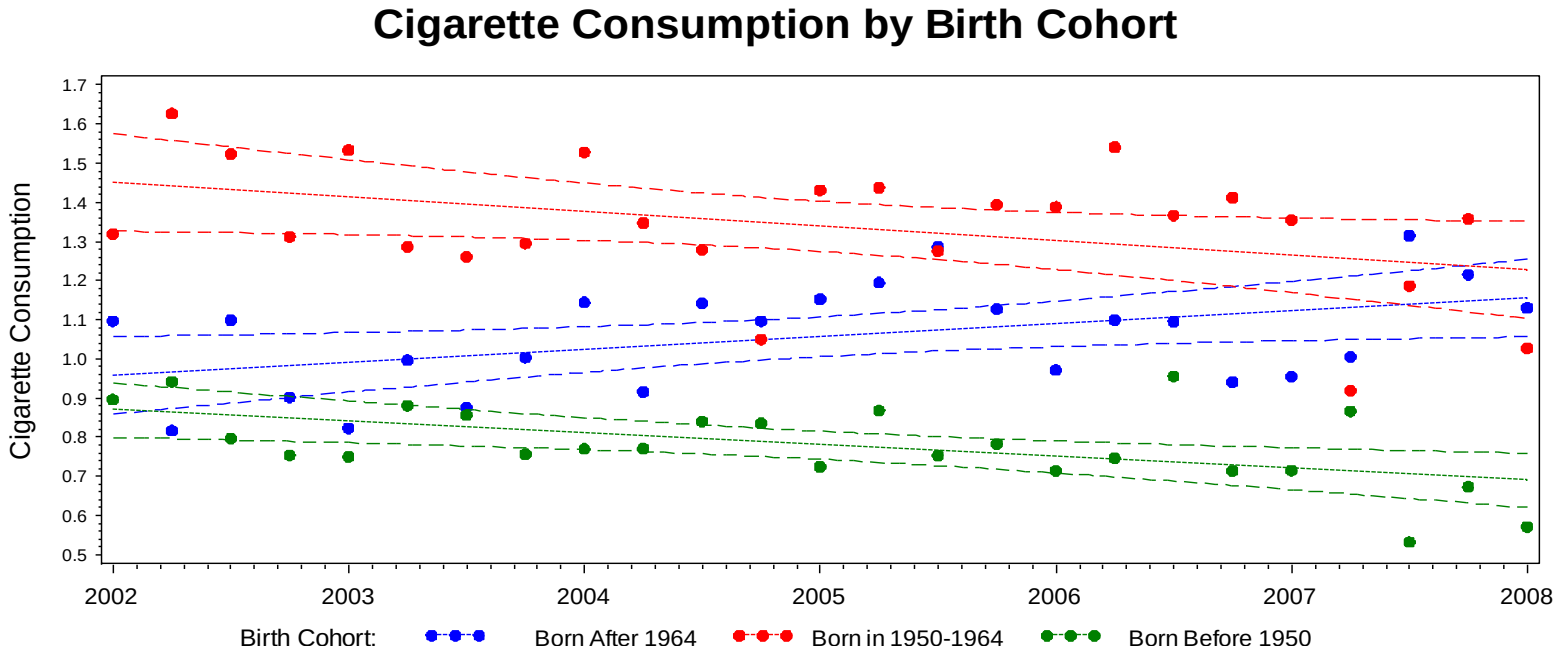

Figure 1.1: 2002-2008 Cigarette Consumption by Birth Cohorts

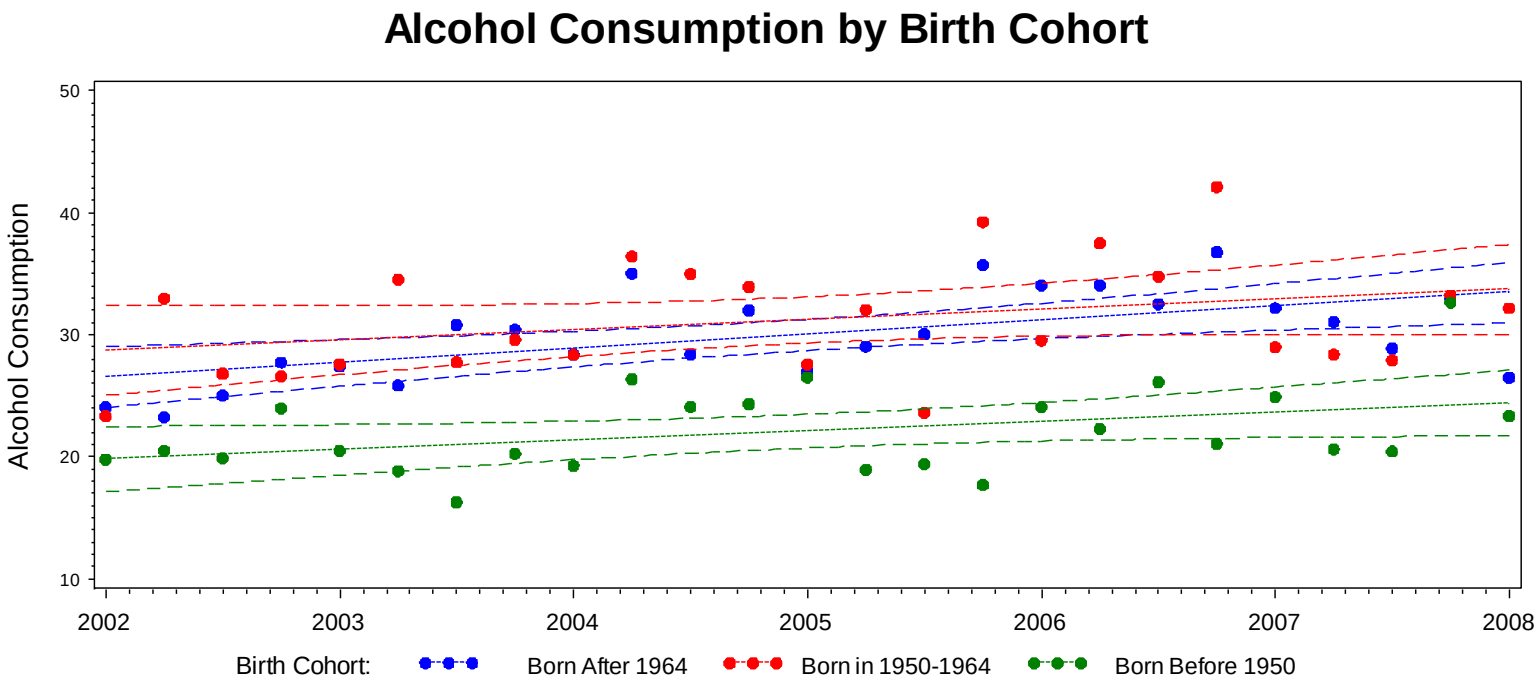

Figure 1.2: 2002-2008 Alcohol Consumption by Birth Cohorts

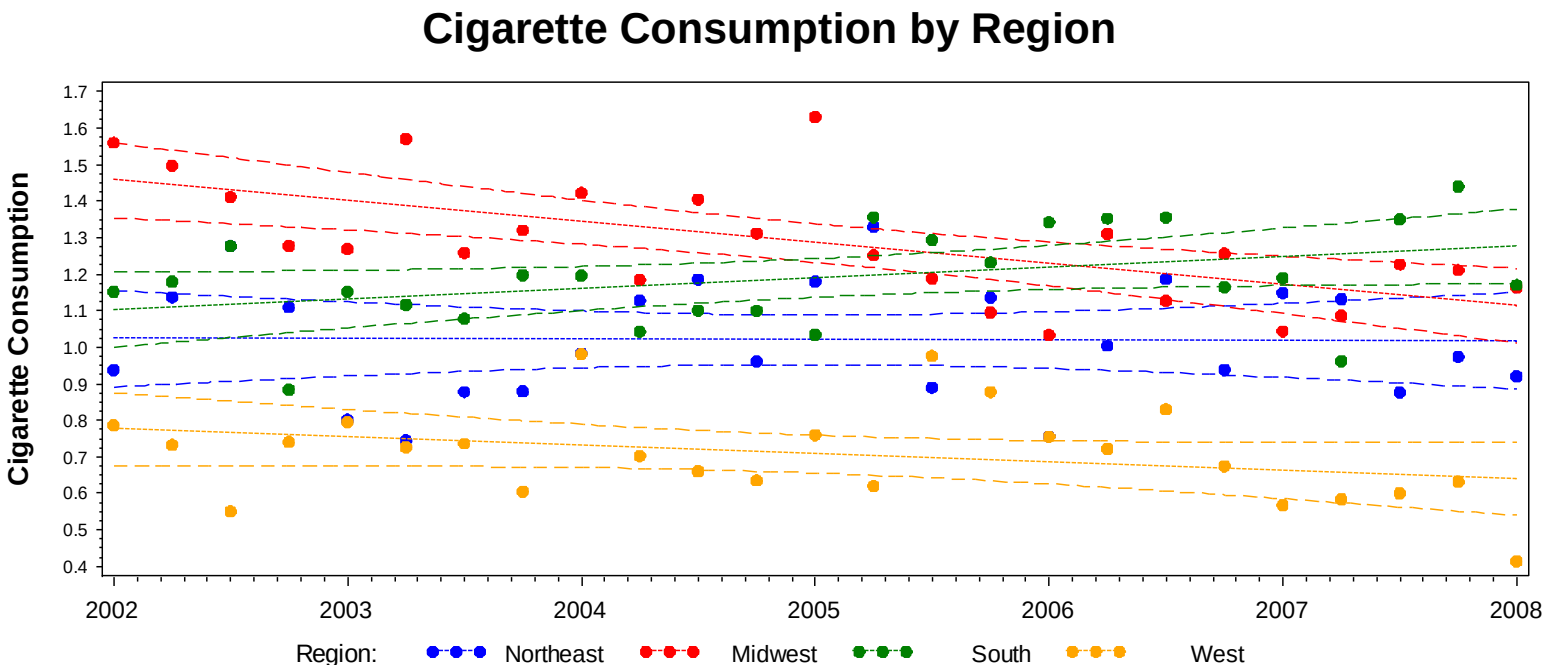

Figure 1.3: 2002-2008 Cigarette Consumption by Region

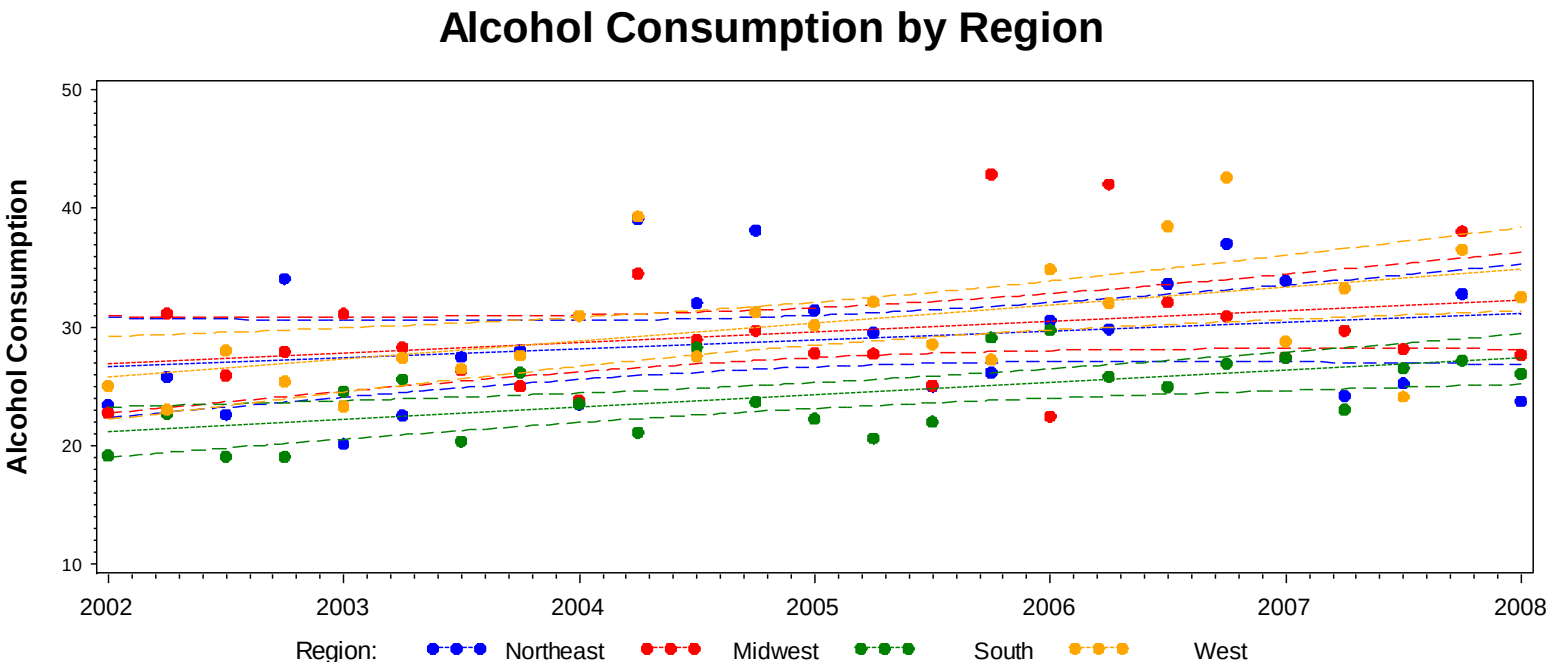

Figure 1.4: 2002-2008 Alcohol Consumption by Region

Table 1.3 . Cigarette and Alcohol Demands Estimated Separately
Interview Data: Within-groups Two-step GMM Method

	(i)		(ii)	
Cigarette				
C_{it-1}	-0.391**	(0.170)	-0.384***	(0.102)
C_{it+1}	-0.511***	(0.106)	-0.458***	(0.075)
A_{it-1}	0.002*	(0.001)	0.002**	(0.001)
A_{it}	0.002**	(0.001)	0.002***	(0.001)
A_{it+1}	0.001	(0.001)	0.001	(0.001)
P_{Ct}	0.052	(0.756)	-0.274	(2.799)
$adj.R^2$	0.36		0.37	
N	25,885		17,444	
Alcohol				
A_{it-1}	-0.214***	(0.028)	-0.190***	(0.028)
A_{it+1}	-0.251***	(0.031)	-0.221***	(0.032)
C_{it-1}	0.528**	(0.241)	0.168*	(0.092)
C_{it}	0.924***	(0.301)	0.219*	(0.125)
C_{it+1}	0.889***	(0.310)	0.254*	(0.131)
P_{At}	-212.715***	(5.846)	-235.154***	(6.517)
$adj.R^2$	0.70		0.74	
N	25,885		17,444	

Notes: All sample is used in (i), CUs who don't have any cigarette or alcohol consumption are dropped in (ii). Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%.

Table 1.4. Cigarette and Alcohol Demands Estimated Separately
Interview Data: 2SLS in First Differences

	(i)		(ii)	
Cigarette				
ΔC_{it-1}	0.127	(0.142)	0.140	(0.146)
ΔC_{it+1}	-0.405	(0.262)	-0.521**	(0.252)
ΔA_{it-1}	0.005	(0.005)	0.004	(0.006)
ΔA_{it}	0.019***	(0.005)	0.019***	(0.006)
ΔA_{it+1}	0.010	(0.007)	0.012	(0.008)
Δp_{Ct}	-6.995*	(3.722)	-9.870*	(5.613)
$adj.R^2$	0.06		0.04	
N	25,885		17,444	
Alcohol				
ΔA_{it-1}	-0.008	(0.026)	-0.002	(0.029)
ΔA_{it+1}	-0.025	(0.041)	-0.028	(0.045)
ΔC_{it-1}	0.672	(0.720)	0.526	(0.725)
ΔC_{it}	1.942	(1.768)	1.689	(1.690)
ΔC_{it+1}	1.610	(1.559)	1.717	(1.597)
Δp_{At}	-201.788***	(8.712)	-202.708***	(9.133)
$adj.R^2$	0.04		0.04	
N	25,885		17,444	

Notes: Instruments include demographics and prices. All sample is used in (i), CUs who don't have any cigarette and alcohol consumption are dropped in (ii). Standard errors are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%.

Table 1.5: Cigarette and Alcohol Demands Estimated Separately
Diary Data: Pseudo-panel Method

Cigarette			*Alcohol*		
Constant	-6.951***	(2.086)	Constant	162.974***	(55.713)
C_{t-1}	0.113**	(0.048)	A_{t-1}	-0.085**	(0.043)
C_{t+1}	0.105**	(0.051)	A_{t+1}	-0.106***	(0.039)
A_{t-1}	-0.001	(0.002)	C_{t-1}	0.189	(1.103)
A_t	0.004*	(0.002)	C_t	2.425**	(1.158)
A_{t+1}	0.003	(0.002)	C_{t+1}	0.236	(1.009)
P_{Ct}	-0.060	(0.088)	P_{At}	-61.703***	(7.109)
I	0.0001	(0.002)	I	0.268***	(0.039)
family size	0.327***	(0.087)	family size	6.867***	(1.881)
white	0.768**	(0.352)	white	37.535***	(7.383)
college	-0.338	(0.324)	college	7.996	(7.435)
adj.R^2	0.67		*adj.*R^2	0.52	

Notes: Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%. The coefficients on cohort dummies are not reported to save space.

Table 1.6. Long-run Elasticities: Separate Demand Equations

ε_{CC}	-0.287	(0.371)
ε_{AA}	-1.339***	(0.201)
ε_{CA}	-0.323**	(0.156)
ε_{AC}	-0.025	(0.042)
ε_{CI}	0.095	(0.080)
ε_{AI}	0.409***	(0.056)

Notes: Elasticities calculated at sample means. Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%.

Table 1.7: Cigarette and Alcohol Demands Estimated as a Semi-reduced System Diary Data: Pseudo-panel Method

Cigarette			*Alcohol*		
Constant	-6.546***	(2.101)	Constant	85.152	(58.083)
C_{t-1}	0.120**	(0.049)	A_{t-1}	-0.082**	(0.043)
C_{t+1}	0.107**	(0.051)	A_{t+1}	-0.097**	(0.038)
A_{t-1}	0.0004	(0.002)	C_{t-1}	0.953	(1.092)
A_{t+1}	0.002	(0.002)	C_{t+1}	0.725	(0.997)
P_{Ct}	-0.085	(0.102)	P_{At}	-74.066***	(8.282)
P_{At}	0.099	(0.363)	P_{Ct}	6.878***	(2.251)
I	0.0001	(0.002)	I	0.267***	(0.038)
family size	0.344***	(0.088)	family size	5.659***	(1.921)
white	0.793**	(0.360)	white	29.419***	(7.889)
college	-0.314	(0.323)	college	6.146	(7.179)
adj.R^2	0.67		*adj.*R^2	0.53	

Notes: Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%. The coefficients on cohort dummies are not reported to save space.

Table 1.8: Long-run Elasticities: Semi-reduced System

ε_{CC}	-0.337	(0.441)
ε_{AA}	-1.591***	(0.240)
ε_{CA}	-0.045	(0.324)
ε_{AC}	0.777***	(0.295)
ε_{CI}	0.089	(0.080)
ε_{AI}	0.408***	(0.056)

Notes: Elasticities calculated at sample means. Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%.

Chapter 2

How do Smoking Bans Affect Restaurant Alcohol Consumption?

2.1. Introduction

On November 23, 1998 US state attorneys general signed a tobacco settlement with the five largest tobacco manufacturers. Since then many US states have also imposed smoking bans in a variety of locations (e.g., restaurants, schools, work places). As more cities and states consider smoking bans, it becomes necessary to analyze the economic impacts of these smoking bans.

Many studies find that smoking bans reduce cigarette consumption (e.g., Yurekli and Zhang, 2000; Gallet, 2004). If cigarette and alcohol are related in consumption, as suggested by some previous studies (e.g., Bask and Melkersson, 2004; Pierani and Tiezzi, 2009), smoking bans are likely to affect alcohol consumption too. In particular, smoking bans at restaurants create a natural experiment for studying the relationship between cigarette and

alcohol consumption. Although there is a vast literature investigating the impact of smoking bans on cigarette consumption, there are only a few studies that analyze the impact of smoking bans on alcohol consumption.

Picone et al. (2004) examine how smoking bans and cigarette prices affect alcohol consumption within a dynamic framework. To account for the addictive nature of these two goods, they add past consumption to the regression models. They find that smoking bans reduce alcohol consumption, but increases in cigarette prices increase alcohol consumption. On the other hand, Gallet and Eastman (2007), using a static model to examine the effects of smoking bans on the state-level demand for beer, wine, and spirits, find that smoking bans at restaurants/bars decrease beer and spirits consumption, but increase wine consumption.

In this study, a rational addiction framework (Becker and Murphy, 1988) is employed to analyze the impact of smoking bans on restaurant alcohol consumption. Consumer Expenditure Survey (CEX), Diary data by U.S. Bureau of Labor Statistics (BLS) is used for the analysis. CEX data are ideal for the purpose of our study as they provide information on alcohol expenditures at restaurants. Thus, rather than analyzing how "overall alcohol consumption" is affected by smoking bans, the focus is given on how "restaurant alcohol consumption" is affected by smoking bans at restaurants. As emphasized by Gallet and Eastman (2007), once a smoking ban is applied to restaurants, it is natural to expect the distribution of customers to shift from smokers towards nonsmokers. Because we have the information on "restaurant alcohol consumption" we are able to analyze how "restaurant alcohol consumption" is affected by this redistribution of customers due to smoking bans.

The Diary Data set is composed of repeated cross sections. Thus, in order to estimate the dynamic demand models, a pseudo panel data approach is employed.

The rest of this paper is organized as follows: Section 2.2 summarizes the rational addiction model, section 2.3 gives a discussion of the data set, section 2.4 explains pseudo-panel approach, section 2.5 presents results, section 2.6 explains policy implications, and section 2.7 concludes the study.

2.2. Theoretical Model

Following Bask and Melkersson (2004), we set the consumer's problem as:

$$\max \quad \sum_{t=1}^{\infty} \beta^{t-1} U(A_{it}, C_{it}, A_{it-1}, C_{it-1}, N_{it}) \tag{2.1}$$

$$s.t. \quad \sum_{t=1}^{\infty} \beta^{t-1} \left(P_{At} A_{it} + P_{Ct} C_{it} + N_{it} \right) = W_i$$

where A_{it} and C_{it} are quantities of alcohol and cigarettes consumed by consumer i at period t; A_{it-1} and C_{it-1} are the habit stocks of alcohol and cigarettes; and N_{it} is the consumption of a non-addictive composite good. $\beta = 1/(1+r)$ with r being the discount rate, P_{At} and P_{Ct} are prices of alcohol and cigarettes, and W_i is the present value of wealth. As in previous studies, we assume that the discount rate is equal to the interest rate. The composite good, *N*, is taken as numeraire.

When the utility function is quadratic, the first-order conditions from (2.1) generate the following structural equations for alcohol and cigarettes, respectively:

$$A_{it} = \beta_{10} + \beta_{11} A_{it-1} + \beta_{12} A_{it+1} + \beta_{13} C_{it-1} + \beta_{14} C_{it} + \beta_{15} C_{it+1} + \beta_{16} P_{At} \quad (2.2)$$

$$C_{it} = \beta_{20} + \beta_{21} C_{it-1} + \beta_{22} C_{it+1} + \beta_{23} A_{it-1} + \beta_{24} A_{it} + \beta_{25} A_{it+1} + \beta_{26} P_{Ct} \quad (2.3)$$

Economic theory implies $\beta_{k6} < 0$ with k =1, 2. Rational addiction implies $\beta_{k1} > \beta_{k2} > 0$ with $\beta_{k1} = (1 + r)\beta_{k2}$. If $\beta_{14} > 0$ and $\beta_{24} > 0$ then drinking and smoking reinforce each other; and if $\beta_{14} < 0$ and $\beta_{24} < 0$ then smoking makes it easier to abstain from drinking, and vice versa.

If $\beta_{13} > 0$, cigarette consumption is a quasi-gateway for alcohol consumption; if $\beta_{23} > 0$, alcohol consumption is a quasi-gateway for cigarette consumption. If there are no quasi-gateway effects, $\beta_{13} = \beta_{15} = \beta_{23} = \beta_{25} = 0$.

The empirical specification is based on the basic specification augmented with individual fixed effects, real income and some exogenous policy variables representing demand shifters:

$$A_{it} = \alpha_{1i} + \beta_{10} + \beta_{11} A_{it-1} + \beta_{12} A_{it+1} + \beta_{13} C_{it-1} + \beta_{14} C_{it} + \beta_{15} C_{it+1} + \beta_{16} P_{At} + \gamma_{11} I_{it} + \gamma_{12} D_{\mathrm{t}} + \gamma_{13} BAC_{\mathrm{t}} + u_{1it} \quad (2.4)$$

$$C_{it} = \alpha_{2i} + \beta_{20} + \beta_{21} C_{it-1} + \beta_{22} C_{it+1} + \beta_{23} A_{it-1} + \beta_{24} A_{it} + \beta_{25} A_{it+1} + \beta_{26} P_{Ct} + \gamma_{21} I_{it} + \gamma_{22} D_{\mathrm{t}} + \gamma_{23} BAC_{\mathrm{t}} + u_{2it} \quad (2.5)$$

where α_i is the individual fixed effect that accounts for unobserved individual heterogeneity, D_t is a vector of two binary variables that show if the state restricted or banned smoking at restaurants, BAC_t is blood alcohol concentration limit for drivers, and I_i is real income after taxes.

We are interested in how restaurant alcohol consumption is affected by smoking bans, so we focus on "restaurant alcohol consumption". Thus, in the empirical specification, A_t refers to "restaurant alcohol consumption".

2.3. Data

2002-2008 CEX Diary Survey data are used. Consumer Unit (CU) expenditures, together with price variables, are used to calculate (average weekly) consumption (i.e., "alcohol consumption at restaurants" = "alcohol expenditures at restaurants"/ "restaurant alcohol prices"). Because state information is used to match CUs with state level cigarette prices, households that have missing state variables are dropped.

Annual state level cigarette prices are collected from the website of Department of Health and Human Services, Centers for Disease Control and Prevention (CDC). To obtain alcoholic beverages prices at restaurants, we construct Lewbel(1989) price indices which enable us to have household specific price variation. Lewbel price indices are calculated from restaurant expenditures of each CU for different subcategories of alcoholic beverages, i.e., beer, wine, spirits. To obtain real prices, all price variables are deflated by "Consumer Price Index (CPI) for all items" reported on the BLS webpage.

Data on clean indoor air laws are collected from the website of CDC. For the purposes of this study, the focus is given on the smoking bans that are applied to restaurants. We create two binary variables showing if, at the time of the survey, the state had restricted (i.e., allowed smoking only in designated areas) or banned smoking in restaurants. Table 2.1 gives

a list of the states that imposed smoking bans at the restaurants over the sample period 2002-2008. State BAC limits for drivers are gathered from Alcohol Policy Information System (APIS) at the National Institute on Alcohol Abuse and Alcoholism (NIAAA) website.

2.4. Methodology

While aggregate data fail to give detailed information about individual behavior, panel surveys generally span short time periods. Deaton (1985) suggested using pseudo-panel approach as an alternative method for estimating individual behavior models. The pseudo-panel approach is an instrumental variables approach in which cohort dummies are used as the instruments. This approach enables one to follow cohorts of people through repeated cross-sectional surveys

Because cohorts are followed over time, they are constructed based on time invariant characteristics, such as the birth year of the reference person. We form pseudo-panels based on the geographic region (northeast, midwest, south, west) and the household head's year of birth (born before 1950, born between 1950-1964, born in 1965 or later). The resulting pseudo-panel consists of a total of 336 observations over 12 cohorts and 28 quarters.

In repeated cross-sectional surveys, at each time period different individuals are observed. Thus, the lagged and lead variables are not observed for the individuals in cohort c at time t. Therefore following previous literature, we replace these variables with the sample means of the individuals at time $t-1$ and $t+1$ respectively. Taking cohort averages of

equations (2.4) - (2.5) over n_c individuals observed in cohort c at time t results in the following equations at the cohort level:

$$\bar{A}_{c(t),t} = \bar{\alpha}_{1c,t} + \beta_{10} + \beta_{11}\bar{A}_{c(t-1),t-1} + \beta_{12}\bar{A}_{c(t+1),t+1} + \beta_{13}\bar{C}_{c(t-1),t-1} + \beta_{14}\bar{C}_{c(t),t} + \beta_{15}\bar{C}_{c(t+1),t+1} + \beta_{16}\bar{P}_{At} + \gamma_{11}\bar{I}_{c(t),t} + \gamma_{12}\bar{D}_{\mathrm{t}} + \gamma_{13}\overline{BAC}_{\mathrm{t}} + \bar{u}_{1c(t),t} \quad (2.6)$$

$$\bar{C}_{c(t),t} = \bar{\alpha}_{2c,t} + \beta_{20} + \beta_{21}\bar{C}_{c(t-1),t-1} + \beta_{22}\bar{C}_{c(t+1),t+1} + \beta_{23}\bar{A}_{c(t-1),t-1} + \beta_{24}\bar{A}_{c(t),t} + \beta_{25}\bar{A}_{c(t+1),t+1} + \beta_{26}\bar{P}_{Ct} + \gamma_{21}\bar{I}_{c(t),t} + \gamma_{22}\bar{D}_{\mathrm{t}} + \gamma_{23}\overline{BAC}_{\mathrm{t}} + \bar{u}_{2c(t),t} \quad (2.7)$$

where $\bar{\alpha}_{c,t}$ is the average of the fixed effects for individuals in cohort *c* at time *t*.

Verbeek and Nijman (1992) explain that if there is sufficient number of observations per cohort, $\bar{\alpha}_{c,t}$ can be treated as the unobserved cohort fixed effect (α_c). They showed that when cohorts contain at least 100 individuals and the time variation in the cohort means is sufficiently large, the bias in the standard fixed effects estimator will be small and can be ignored. In that case, models can be estimated at the cohort level by adding cohort dummies or cohort fixed effects. McKenzie (2004) shows that in dynamic pseudo-panel data models, the fixed effects estimator on cohort averages is consistent when $n_c \to \infty$. In our sample, the number of observations in each cohort is sufficiently large (i.e., around 100 observations), so the fixed effects estimator is applied to cohort averages. The number of households in each cohort and time period is not the same which might induce heteroskedasticity. Following Dargay (2007), to correct for heteroskedasticity, all cohort level variables are weighted by the square root of the number of households in each cohort. To have consistent standard errors, bootstrapped standard errors are calculated (1000 replications).

2.5. Empirical Results

First, equations (2.6) - (2.7) are estimated as separately. The results are shown in Table 2.2. Own price has a negative coefficient in both equations, but it is only significant in alcohol equation. Both cigarette and alcohol consumptions are consistent with rational addiction (i.e., lag and lead consumption coefficients are positive). Discount rates are positive (i.e., the coefficient on lag consumption is higher than the coefficient on lead consumption).

In the alcohol equation, current cigarette consumption has a positive and significant coefficient which suggests cigarette consumption reinforces alcohol consumption. In the cigarette equation, current alcohol consumption has a positive coefficient which suggests alcohol consumption reinforces cigarette consumption. We have not found any support for quasi-gateway effect across cigarette and alcohol consumptions. Lagged cigarette (alcohol) consumption in the alcohol (cigarette) equation is not significant.

Cohort fixed effects are jointly significant in both equations (i.e., the F-test is at the 1% level where F-values are 7.26 and 5.61 in alcohol and cigarette equations, respectively). Higher BAC limits increase restaurant alcohol consumption. Higher BAC limits also increase cigarette consumption, which suggests that alcohol consumption reinforces cigarette consumption.

Smoking bans and restrictions in restaurants decrease overall cigarette consumption, but the effect is not statistically significant. On the other hand, smoking bans and restrictions at restaurants increase restaurant alcohol consumption and the coefficient is statistically significant. After a smoking ban, even if smokers decrease alcohol consumption in

restaurants the increase in the consumption of nonsmokers could be more than the decrease in the consumption of smokers, causing the net effect of a smoking ban in restaurants to increase alcohol consumption.

When making consumption decisions regarding different addictive goods, it is not clear whether the degree of forward-looking behavior is the same. We impose the restriction that the discount factor is homogenous and reestimated the equations. The results are shown in the second column of Table 2.2. There is no major change in the coefficients.

As we noted earlier, our results do not provide support for quasi-gateway effects. If there are no quasi-gateway effects, the model can be simplified by setting $\beta_{13} = \beta_{15} = \beta_{23} = \beta_{25} = 0$. We also estimated equations imposing this restriction. The results are shown in the third column of Table 2.3. Again, there are no major changes in the coefficients.

As pointed out by Bask and Melkersson (2004), decisions regarding cigarette and alcohol consumption are often determined jointly. Thus following previous literature, we combine equations (2.6) - (2.7) to obtain a semi-reduced system:

$$\bar{A}_{ct} = \alpha_{3c} + \beta_{30} + \beta_{31}\bar{A}_{ct-1} + \beta_{32}\bar{A}_{c\,t+1} + \beta_{33}\bar{C}_{ct-1} + \beta_{34}\bar{C}_{ct+1} + \beta_{35}P_{At} + \beta_{36}P_{Ct} + \gamma_{31}\bar{I}_{ct} + \gamma_{32}\bar{D}_t + \gamma_{33}\overline{BAC}_t + \bar{u}_{3ct} \quad (2.8)$$

$$\bar{C}_{ct} = \alpha_{4c} + \beta_{40} + \beta_{41}\bar{C}_{ct-1} + \beta_{42}\bar{C}_{ct+1} + \beta_{43}\bar{A}_{ct-1} + \beta_{44}\bar{A}_{ct+1} + \beta_{45}P_{Ct} + \beta_{46}P_{At} + \gamma_{41}\bar{I}_{ct} + \gamma_{42}\bar{D}_t + \gamma_{43}\overline{BAC}_t + \bar{u}_{4ct} \quad (2.9)$$

The systems of demand equations are estimated using iterated seemingly unrelated regression (ITSUR). The results are shown in Table 2.4. The long-run price and income elasticities calculated at the sample mean are shown in Table 2.4. Long-run own price

elasticities are negative for both goods. Long-run cigarette demand is inelastic while long-run restaurant alcohol demand is elastic.

The income elasticity is positive and less than one for cigarettes but it is greater than one for restaurant alcohol demand. Both income elasticities are significant. This finding suggests that restaurant alcohol consumption is a luxury good while cigarettes are a normal good.

Cross-price elasticities are positive for both goods, but only the cross-price elasticity of alcohol with respect to cigarette price is significant. Our results are consistent with that of Goel and Morey (1995); the cross-price elasticity of alcohol is larger than the cross-price elasticity of cigarette with both elasticities being positive.

Picone et al.(2004) claim that although alcohol and cigarettes can complement each other for social drinkers, they are gross substitutes in price. As cigarette prices increase many smokers reduce or quit smoking and substitute alcohol for cigarette as a source of pleasure. In addition, as cigarette expenditures decrease alcohol consumption increases due to positive income effect given that alcohol is a normal good. In an analysis of smoking and drinking participation, Decker and Schwartz (2000) come up with a similar explanation.

We believe that while cigarettes and alcohol reinforce each other in consumption, they are substitutes in prices. Increasing cigarette prices will give smokers an incentive to cut cigarette consumption given that smoking is associated with serious health problems. As mentioned in Picone et al.(2004) and Decker&Schwartz (2000), people who quit smoking are likely to compensate the induced stress by increasing alcohol consumption.

2.6. Policy Implications of Smoke-free Laws

By reducing exposure to second-hand smoke, smoking bans decrease the negative externalities created by smoking behavior. However, the tobacco industry has constantly attacked smoking bans claiming that smokers will be driven away from restaurants and bars; and the establishments will lose revenue. Bar and restaurant owners have also voiced concerns on the possible adverse effects of smoking bans on the revenues. Contrary to these concerns, studies published in peer-reviewed journals have either found an increase in the restaurant/bar revenues after a smoking ban (Cowling and Bond, 2005; Glantz, 2000), or failed to find any statistically significant effect (Bartosch and Pope, 2002; Hyland at al., 1999). Gallet and Eastman (2007), using a static model, find that smoking bans at restaurants/bars decrease overall (i.e., at home and restaurants) beer and spirits consumption, but increase overall (i.e., at home and restaurants) wine consumption.

In the current study, it is found that smoking bans increase restaurant alcohol consumption overall. There might be two different effects going on. As pointed out by previous studies, prior to a smoking ban, individuals who are sensitive to second-hand smoke are likely to avoid public places in which smoking is allowed. Once a smoking ban is implemented in restaurants, these individuals are likely to go to restaurants more often and stay longer which leads to an increase in their restaurant alcohol consumption. Moreover, because smoking is no longer allowed in the restaurants after a smoke-free law, smokers are likely to engage in a compensating behavior and consume more alcohol while they are in these establishments.

2.7. Concluding Remarks

In recent years, more and more U.S. states have imposed smoking bans in a variety of locations including restaurants. If cigarette and alcohol are related in consumption as suggested by previous studies, smoking bans in restaurants are likely to affect restaurant alcohol consumption too. In this study, employing a pseudo-panel data approach within a rational addiction framework, we analyze the effects of smoking bans at restaurants on restaurant alcohol consumption. We found that cigarette and alcohol consumptions are consistent with rational addiction. The structural specification suggests cigarettes and alcohol reinforce each other in consumption, whereas the cross-price elasticities derived from semi-reduced demand system suggest substitutability due to price changes. Our findings are consistent with Picone et al.(2004) who also found people respond differently to physical restrictions/conditions and changes in prices. We believe that even if drinking reinforces smoking and vice versa, when there are permanent price changes, consumers adjust their behavior and reallocate their spending on these two goods. Especially when cigarette prices increase, it is expected that many people decrease cigarette consumption or quit completely, which would accelerate stress levels given that cigarette is a highly addictive substance. Thus, it is very plausible to expect that these people would increase their alcohol consumption to cope with the resulting stress.

Our findings suggest useful public policy implications. Although cigarette taxation has been cited as an effective public policy tool for cigarette control, our results suggest that increasing cigarette prices would increase alcohol consumption (the cross-price elasticity of

alcohol with respect to the cigarette prices is positive). There is a similar trade-off when smoking bans are imposed. Although restaurant smoking bans decrease smoking, they increase overall restaurant alcohol consumption. On the other hand, when BAC limits decrease, both alcohol and cigarette consumption decrease. Reducing the BAC limit would reduce the consumption of alcohol in restaurants and bars. Because drinking reinforces smoking, decreasing the BAC limit would also decrease cigarette consumption. Reducing the BAC limit and increasing road controls would also eliminate negative externalities such as fatalities due to drunk driving.

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Tables

Table 2.1. Smoking Bans (at Restaurants) over 2002- 2008 period

2002	2003	2004	2005	2006	2007	2008
Utah	Utah	Utah	Utah	Utah	Utah	Utah
Delaware	Delaware	Delaware	Delaware	Delaware	Delaware	Delaware
	New York	New York	New York	New York	New York	New York
	Florida	Florida	Florida	Florida	Florida	Florida
		Maine	Maine	Maine	Maine	Maine
		Idaho	Idaho	Idaho	Idaho	Idaho
		Massachusetts	Massachusetts	Massachusetts	Massachusetts	Massachusetts
			Rhode Island	Rhode Island	Rhode Island	Rhode Island
			Montana	Montana	Montana	Montana
			Washington	Washington	Washington	Washington
				New Jersey	New Jersey	New Jersey
				Colorado	Colorado	Colorado
				Hawaii	Hawaii	Hawaii
				Ohio	Ohio	Ohio
				Neveda	Neveda	Neveda
					Dictrict of Columbia	Dictrict of Columbia
					Louisiana	Louisiana
					Oregon	Oregon
					Tennessee	Tennessee
					New Hampshire	New Hampshire
					Minnesota	Minnesota
						Illinois
						Maryland
						Iowa
						Pennsylvania

Table 2.2. Alcohol and Cigarette Demands Estimated Separately

Alcohol at restaurants	*Quasi-gateway allowed*		*Homogen. Discounting*		*No quasi-gateway eff.*	
Constant	-1.335	(15.413)	-1.333	(15.431)	-1.382	(15.277)
A_{t-1}	0.091*	(0.048)	0.090*	(0.048)	0.093*	(0.048)
A_{t+1}	0.053	(0.046)	0.054	(0.045)	0.050	(0.045)
C_{t-1}	0.057	(0.330)	0.058	(0.330)	-	
C_t	0.817**	(0.390)	0.817**	(0.390)	0.800**	(0.384)
C_{t+1}	-0.190	(0.365)	-0.191	(0.364)	-	
P_{At}	-19.938***	(3.056)	-19.938***	(3.056)	-20.011***	(3.040)
I	0.130***	(0.016)	0.130***	(0.016)	0.129***	(0.016)
banned	7.437***	(1.318)	7.437***	(1.318)	7.517***	(1.285)
restricted	8.773***	(1.695)	8.772***	(1.695)	8.875***	(1.667)
BAC	118.054***	(28.382)	118.070***	(28.373)	117.414***	(28.305)
adj.R^2	0.59		0.59		0.59	

Cigarette	*Quasi-gateway allowed*		*Homogen. Discounting*		*No quasi-gateway eff.*	
Constant	-8.472***	(1.992)	-8.508***	(1.982)	-8.470***	(1.999)
C_{t-1}	0.149***	(0.050)	0.166***	(0.054)	0.139***	(0.049)
C_{t+1}	0.128**	(0.051)	0.100**	(0.047)	0.128**	(0.050)
A_{t-1}	-0.006	(0.006)	-0.006	(0.006)	-	-
A_t	0.010	(0.007)	0.010	(0.007)	0.010	(0.007)
A_{t+1}	-0.0001	(0.006)	0.0004	(0.006)	-	-
P_{Ct}	-0.045	(0.091)	-0.042	(0.092)	-0.047	(0.091)
I	0.004**	(0.002)	0.004**	(0.002)	0.004**	(0.002)
banned	-0.106	(0.180)	-0.114	(0.179)	-0.148	(0.170)
restricted	-0.023	(0.250)	-0.035	(0.249)	-0.066	(0.243)
BAC	14.973***	(3.910)	15.047***	(3.922)	15.393***	(3.882)
adj.R^2	0.67		0.67		0.68	

Notes: Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, ** denotes significance at 5%, * denotes significance at 10%. The coefficients on cohort dummies are not reported to save space.

Table 2.3. Long-run Elasticities:
Separate Demand Equations

	Quasi-gateway allowed		Homogen. Discounting		No quasi-gateway eff	
ε_{AA}	-3.079***	(0.550)	-3.080***	(0.550)	-3.107***	(0.547)
ε_{CC}	-0.228	(0.381)	-0.212	(0.377)	-0.238	(0.381)
ε_{AC}	-0.028	(0.062)	-0.026	(0.061)	-0.034	(0.052)
ε_{CA}	-0.118	(0.246)	-0.116	(0.245)	-0.269	(0.175)
ε_{AI}	1.168***	(0.112)	1.167***	(0.112)	1.174***	(0.111)
ε_{CI}	0.312***	(0.097)	0.310***	(0.096)	0.344***	(0.094)

Notes: Elasticities are calculated at sample means. Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, ** denotes significance at 5%, * denotes significance at 10%.

Table 2.4. Alcohol and Cigarette Demands Estimated as a Semi-reduced System

Alcohol at restaurants			*Cigarette*		
Constant	-22.279	(15.281)	Constant	-9.152***	(2.036)
A_{t-1}	0.085*	(0.048)	C_{t-1}	0.152***	(0.050)
A_{t+1}	0.053	(0.045)	C_{t+1}	0.125**	(0.051)
C_{t-1}	0.359	(0.322)	A_{t-1}	-0.005	(0.006)
C_{t+1}	-0.010	(0.356)	A_{t+1}	0.0003	(0.006)
P_{At}	-26.408***	(3.544)	P_{Ct}	-0.068	(0.103)
P_{Ct}	3.109***	(0.745)	P_{At}	0.250	(0.459)
I	0.126***	(0.015)	I	0.005***	(0.002)
banned	6.863***	(1.246)	banned	-0.080	(0.179)
restricted	7.845***	(1.659)	restricted	0.069	(0.247)
BAC	79.207***	(27.714)	BAC	13.393***	(4.436)
adj.R^2	0.60		adj.R^2	0.67	

Notes: Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, ** denotes significance at 5%, * denotes significance at 10%. The coefficients on cohort dummies are not reported to save space.

Table 2.5: Long-run Elasticities: Semi-reduced System

ε_{AA}	-4.000***	(0.643)
ε_{CC}	-0.436	(0.453)
ε_{AC}	2.032***	(0.514)
ε_{CA}	0.468	(0.516)
ε_{AI}	1.104***	(0.106)
ε_{CI}	0.280***	(0.098)

Notes: Elasticities calculated at sample means. Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%.

Chapter 3

Rationally Addicted to Cigarettes, Alcohol and Coffee?

3.1 Introduction

The rational addiction model (Becker and Murphy, 1988) is the most popular framework used to estimate the demand for addictive goods. In myopic demand models of addictive behavior, past consumption increases current consumption, but consumers do not take into account the future consequences of their actions when they make current consumption decisions. In the rational addiction model, the consumer is aware of the future consequences of addiction and accounts for them when making consumption choices. In the rational addiction model, both past and anticipated future consumption affect current consumption positively.

Bask and Melkersson (2004) extended the rational addiction model to allow for commodity addictions in two addictive goods: alcohol and cigarettes. This paper extends

their model by analyzing the interdependence among three addictive goods in a rational addiction framework: cigarettes, alcohol and coffee.

The rational addiction model has been previously applied to cigarette consumption (e.g., Becker et al., 1994), alcohol consumption (e.g., Grossman et al., 1998) and coffee consumption (e.g., Olekalns and Bardsley, 1996), separately. Many papers claim interdependence between cigarette and alcohol consumption using the myopic or rational addiction models. On the other hand, to the best of our knowledge, there is no paper that analyzes the relationship between the consumption of coffee and other addictive goods like cigarettes and alcohol.

Zavela et al. (1990) examined the relation between cigarettes, alcohol, and coffee consumption among army personnel. They found that, for women, cigarette and alcohol consumption are positively correlated; but, for men, cigarette and coffee consumption are positively correlated. In addition, they found a pattern of abstention from alcohol and coffee among nonsmokers.

In this paper, we analyze the relationship between cigarettes, alcohol and coffee consumption in a rational addiction framework using a pseudo-panel data approach. The objectives of this study are twofold: First, to gain more insight into behavioral processes concerning cigarettes, alcohol and coffee consumption; second, to generalize the rational addiction model to include three addictive goods to provide a framework for future research in the related literature (e.g., interdependence among cigarettes, alcohol and marijuana or interdependence among cigarettes and different types of alcoholic beverages such as beer and wine).

This paper is organized as follows: Section 3.2 explains the rational addiction model and extends it to three addictive goods; section 3.3 presents the data; section 3.4 explains pseudo-panel approach; section 3.5 summarizes the results; and section 3.6 concludes the study.

3.2. Theoretical Model

Following Bask and Melkersson (2004), we assume:

$$U_{it} = U(C_{it}, A_{it}, K_{it}, S_{it}, D_{it}, L_{it}, N_{it}) \quad (3.1)$$

where C_{it}, A_{it} and K_{it} are the quantities of cigarettes, alcohol and coffee consumed; S_{it}, D_{it} and L_{it} are the habit stocks of cigarettes, alcohol and coffee respectively; N_{it} is the consumption of a non-addictive composite good.

We assume a strictly concave utility function. The marginal utility derived from each good is assumed to be positive (i.e., $U_C > 0$, $U_A > 0$, $U_K > 0$ and $U_N > 0$; concavity implies $U_{CC} < 0$, $U_{AA} < 0$, $U_{KK} < 0$ and $U_{NN} < 0$). Following the rational addiction literature, we assume that habit stocks of cigarettes and alcohol affect current utility negatively due to their adverse health effects (i.e., U_S<0 and $U_D < 0$; concavity implies $U_{SS} < 0$ and $U_{DD} < 0$). Since coffee use is not associated with adverse health effects, we don't impose any assumptions on the marginal utility of habit stocks of coffee.

Reinforcement implies $U_{CS} > 0$, $U_{AD} > 0$ and $U_{KL} > 0$. Cigarette, alcohol and coffee consumption are assumed to have no effect on the marginal utility derived from the consumption of the composite good (i.e., $U_{CN} = U_{AN} = U_{KN} = U_{SN} = U_{DN} = U_{LN} = 0$).

If alcohol (cigarette) consumption decreases the marginal utility derived from cigarette (alcohol) consumption, $U_{CA} < 0$ and $U_{SD} < 0$; if alcohol consumption reinforces cigarette consumption and vice versa, $U_{CA} > 0$ and $U_{SD} > 0$.

If past alcohol consumption increases the marginal utility from current cigarette consumption, $U_{CD} > 0$; if past cigarette consumption increases the marginal utility from current alcohol consumption, $U_{AS} > 0$. Pierani and Tiezzi (2009) name this intertemporal cross-reinforcement effect the quasi-gateway effect.[9] When cigarette consumption does not affect the marginal utility from alcohol consumption and vice versa $U_{CA} = U_{SD} = U_{AS} = U_{CD} = 0$

If coffee consumption reinforces cigarette consumption, $U_{CK} > 0$ and $U_{SL} > 0$; and if coffee consumption decreases the marginal utility from alcohol consumption, $U_{AK} < 0$ and $U_{DL} < 0$. When consumption of coffee does not affect the marginal utility from cigarette consumption, $U_{CK} = U_{SL} = U_{CL} = U_{KS} = 0$. When consumption of coffee does not affect the marginal utility from alcohol consumption, $U_{AK} = U_{DL} = U_{AL} = U_{KD} = 0$.

The intertemporal budget constraint is

$$\sum_{t=1}^{\infty} \beta^{t-1} \left(P_{Ct} C_{it} + P_{At} A_{it} + P_{Kt} K_{it} + N_{it} \right) = W_i \qquad (3.2)$$

where $\beta = 1/(1+r)$ with r being the discount rate, P_{Ct}, P_{At} and P_{Kt} are prices of cigarettes, alcohol and coffee, respectively, and W_i is the present value of wealth. The composite good, *N*, is taken as the numeraire good.

[9] A true gateway effect refers to the condition that consumption of one addictive substance leads to later *initiation* of another addictive substance (Pacula,1997).

Then the consumer's problem is:

$$\max \quad \sum_{t=1}^{\infty} \beta^{t-1} U\left(C_{it}, A_{it}, K_{it}, S_{it}, D_{it}, L_{it}, N_{it}\right)$$

$$s.t. \quad \sum_{t=1}^{\infty} \beta^{t-1} \left(P_{Ct} C_{it} + P_{At} A_{it} + P_{Kt} K_{it} + N_{it} \right) = W_i \tag{3.3}$$

As in previous studies, we assume that $S_{it} = C_{it-1}$, $D_{it} = A_{it-1}$ and $L_{it} = K_{it-1}$. When the utility function is quadratic, the solution to problem (3.3) generates the following demand equations[10]:

$$C_{it} = \alpha_{1i} + \beta_{10} + \beta_{11} C_{it-1} + \beta_{12} C_{it+1} + \beta_{13} A_{it-1} + \beta_{14} A_{it} + \beta_{15} A_{it+1} + \beta_{16} K_{it-1} + \beta_{17} K_{it} + \beta_{18} K_{it+1} + \beta_{19} P_{Ct} + \gamma_1 X_{it} + u_{1it} \tag{3.4}$$

$$A_{it} = \alpha_{2i} + \beta_{20} + \beta_{21} A_{it-1} + \beta_{22} A_{it+1} + \beta_{23} C_{it-1} + \beta_{24} C_{it} + \beta_{25} C_{it+1} + \beta_{26} K_{it-1} + \beta_{27} K_{it} + \beta_{28} K_{it+1} + \beta_{29} P_{At} + \gamma_2 X_{it} + u_{2it} \tag{3.5}$$

$$K_{it} = \alpha_{3i} + \beta_{30} + \beta_{31} K_{it-1} + \beta_{32} K_{it+1} + \beta_{33} C_{it-1} + \beta_{34} C_{it} + \beta_{35} C_{it+1} + \beta_{36} A_{it-1} + \beta_{37} A_{it} + \beta_{38} A_{it+1} + \beta_{39} P_{Kt} + \gamma_3 X_{it} + u_{3it} \tag{3.6}$$

As pointed out by Bask and Melkersson (2004), the rational addiction model nests many different behaviors: "A non-addicted consumer responds only to information in the current period, which means that the parameters for those variables which correspond to the past and the future are zero. An addicted but myopic consumer also responds to past information. Finally, an addicted consumer who is also rational responds to past, current, and future information" (p.375). The specification also allows for quasi-gateway effects across different

[10] See Appendix D for derivation of Equations (3.4)-(3.6).

addictive goods. The nested structure is convenient for testing certain parameter restrictions to evaluate the merits of a generalization.

In the empirical model, in addition to the variables that directly come from the theoretical model, for each equation we add an error term (u_{it}), some consumer demographics (X_{it}) and an individual fixed effect (α_i) to account for unobserved individual heterogeneity, such as attitudes towards health risks.

For k=1,2,3 economic theory implies $\beta_{k9} < 0$. Rational addiction implies $\beta_{k1} > \beta_{k2} > 0$ with $\beta_{k1} = (1 + r)\beta_{k2}$. From the structural parameters, the rate of time preference can be derived for each good[11]. In the applied literature, these parametric restrictions have been tested to check the validity of the rational addiction model.

For k=1,2, $\beta_{k4} > 0$ if smoking and drinking reinforce each other; and $\beta_{k4} < 0$ if drinking makes it easier to abstain from smoking, and vice versa. If $\beta_{13} > 0$ alcohol consumption is a quasi-gateway for cigarette consumption, if $\beta_{23} > 0$ cigarette consumption is a quasi-gateway for alcohol consumption.

If $\beta_{34} > 0$ then coffee and cigarette consumption reinforce each other. If $\beta_{37} < 0$ then coffee consumption makes it easier to abstain from alcohol consumption.

[11] In empirical applications it is possible to find different rate of time preference, r, for different addictive goods.

3.3. Data

Consumer Expenditure Survey(CEX) Diary data by Bureau of Labor Statistics(BLS) are used in this study. Cigarette, alcohol and coffee expenditures, together with price variables, are used to calculate (average weekly) consumptions (i.e., cigarette consumption= cigarette expenditure/ cigarette price). The observations with missing state variables are dropped. To avoid any inconsistency, we also dropped the very few households that report different household head demographics (i.e., race, education) for each week that the Diary data are collected.

Because price data are not collected by CEX, price variables used in the analysis are gathered from other data sources. All price variables are deflated by the CPI for all items reported on the BLS webpage. Annual state level cigarette prices are gathered from the website of Department of Health and Human Services, Centers for Disease Control and Prevention (CDC). To obtain alcoholic beverages prices, we construct Lewbel (1989) price indices that have household specific price variation. Regional coffee prices reported monthly on the BLS webpage are used to obtain quarterly coffee prices[12].

[12] Regional coffee prices are not reported for the most recent years, we derived those using monthly coffee price index and the previous month's coffee price.

3.4. Methodology

We use a pseudo-panel approach (see Deaton, 1985). Cohorts are constructed based on the geographic region (northeast, midwest, south, west) and the household head's year of birth (born before 1950, born between 1950-1964, born in 1965 or later). The resulting pseudo-panel consists of a total of 336 observations over 12 cohorts (4 regions times 3 generations) and 28 quarters (from the first quarter of 2002 to the last quarter of 2008).

Because pseudo-panel approach is an IV method, the time-invariant instruments should have correlation not only with the lagged and lead consumption variables but also with the exogenous variables in the model (see Verbeek and Vella, 2005). Thus we limit the number of demographic variables that we include in the model.

In repeated cross-sectional surveys, different individuals are observed at each time period. As a result, the lagged and lead variables are not observed for the same individuals in cohort c at time t. Therefore following the previous literature, we replace these sample means of the unobserved variables with the sample means of the individuals at time t−1, and t+1, respectively. Taking cohort averages of equations (3.4) - (3.6) over n_c individuals observed in cohort c at time t results in:

$$\begin{aligned}\bar{C}_{c(t),t} = {} & \bar{\alpha}_{1c,t} + \beta_{10} + \beta_{11}\,\bar{C}_{c(t-1),t-1} + \beta_{12}\bar{C}_{c(t+1),t+1} + \beta_{13}\bar{A}_{c(t-1),t-1} + \beta_{14}\bar{A}_{c(t),t} \\ & + \beta_{15}\bar{A}_{c(t+1),t+1} + \beta_{16}\bar{K}_{c(t-1),t-1} + \beta_{17}\bar{K}_{c(t),t} + \beta_{18}\bar{K}_{c(t+1),t+1} + \beta_{19}\,P_{Ct} \\ & + \gamma_1\bar{X}_{c(t),t} + \bar{u}_{1c(t),t} \qquad (3.7)\end{aligned}$$

$$\bar{A}_{c(t),t} = \bar{\alpha}_{2c,t} + \beta_{20} + \beta_{21}\bar{A}_{c(t-1),t-1} + \beta_{22}\bar{A}_{c(t+1),t+1} + \beta_{23}\bar{C}_{c(t-1),t-1} + \beta_{24}\bar{C}_{c(t),t}$$
$$+\beta_{25}\bar{C}_{c(t+1),t+1} + \beta_{26}\bar{K}_{c(t-1),t-1} + \beta_{27}\bar{K}_{c(t),t} + \beta_{28}\bar{K}_{c(t+1),t+1} + \beta_{29}P_{At}$$
$$+ \gamma_2\bar{X}_{c(t),t} + \bar{u}_{2c(t),t} \quad (3.8)$$

$$\bar{K}_{c(t),t} = \bar{\alpha}_{3c,t} + \beta_{30} + \beta_{31}\bar{K}_{c(t-1),t-1} + \beta_{32}\bar{K}_{c(t+1),t+1} + \beta_{33}\bar{C}_{c(t-1),t-1} + \beta_{34}\bar{C}_{c(t),t}$$
$$+\beta_{35}\bar{C}_{c(t+1),t+1} + \beta_{36}\bar{A}_{c(t-1),t-1} + \beta_{37}\bar{A}_{c(t),t} + \beta_{38}\bar{A}_{c(t+1),t+1} + \beta_{39}P_{Kt}$$
$$+ \gamma_3\bar{X}_{c(t),t} + \bar{u}_{3c(t),t} \quad (3.9)$$

where $\bar{\alpha}_{c,t}$ is the average of the fixed effects for those individuals in cohort *c* at time *t*.

Because the sample is collected separately for different time periods, $\bar{\alpha}_{c,t}$ is not constant over time. If there are sufficient observations in each cohort, $\bar{\alpha}_{c,t}$ can be treated as unobserved cohort fixed effect, α_c (see Verbeek and Nijman, 1992). In that case, we can estimate the demand equations at the cohort level by using cohort dummies or cohort fixed effects. In the dynamic pseudo-panel data model, the fixed effects estimator on cohort averages is consistent when $n_c \to \infty$ (McKenzie 2004). The number of observations in each cohort is sufficiently large in our sample (i.e., around 100 observations). Thus the fixed effects estimator on cohort averages is used. In the sample, the number of households in each cohort is not the same which might induce heteroskedasticity. To correct for heteroskedasticity, following Dargay (2007), all cohort variables are weighted by the square root of the number of households in each cohort. Bootstrapped standard errors are calculated (1000 replications).

3.5. Empirical Results

First, each equation in (3.10) - (3.12) is estimated as a separate equation. The results are shown in Table 3.1. Both cigarette and coffee demands are consistent with rational addiction (i.e., lag and lead consumption coefficients are positive and significant). In both equations the coefficient on lag consumption is higher than the lead consumption coefficient, implying the rate of intertemporal preference is positive. In alcohol demand, lag and lead consumptions have negative coefficients. This result might be due to inventory effects. In the alcohol demand equation, current cigarette consumption has a positive and significant coefficient suggesting that current cigarette consumption reinforces current alcohol consumption. We have not found any proof of quasi-gateway effects across cigarette and alcohol consumptions.[13] Lag alcohol (cigarette) consumption in the cigarette (alcohol) demand equation is not significant. In coffee demand, the coefficients on current cigarette and current alcohol consumptions are positive, but not statistically significant.

The implied discount rates, r, are derived from the parameter estimates of own lagged and lead consumption ($i.e.\ \beta_1 = (1+r)\beta_2$). They are positive and plausible for cigarette and coffee consumption. It is 4.57% for cigarette consumption and 1.91% for coffee consumption. Because cigarettes are more addictive than coffee, consumers of cigarettes are likely to be more myopic than consumers of coffee.

[13] Failure to find evidence for quasi-gateway effects does not mean that there are no true gateway effects. Our results do not rule out the possibility that consumption of one substance leads to *initiation* of use of another substance. Unfortunately, the way the model is formulated does not make it possible to test for these true gateway effects.

Regarding demographics, as family size increases cigarette and alcohol consumptions increase. Whites have a higher consumption of cigarettes and alcohol compared to other races. The consumer units whose household head has at least an associate's degree smoke less cigarettes, but drink more alcohol and coffee compared to other consumer units. However the effect of education on consumption is not statistically significant. Overall, consumer demographics do not seem to affect coffee consumption significantly. On the other hand, cohort fixed effects are jointly significant in all three equations. The p-value for the F-test is smaller than 1% suggesting one should account for unobserved cohort fixed effects (F-values are 7.02, 3.53 and 3.45 for cigarettes, alcohol and coffee, respectively).

Bask&Melkersson (2004) and Pierani&Tiezzi (2009) point out that decisions regarding cigarette and alcohol consumptions are often made jointly. Thus following Bask and Melkersson (2004), we combine equations (3.10) - (3.12) to estimate a semi-reduced system.

$$\bar{C}_{ct} = \alpha_{4c} + \beta_{40} + \beta_{41}\bar{C}_{ct-1} + \beta_{42}\bar{C}_{ct+1} + \beta_{43}\bar{A}_{ct-1} + \beta_{44}\bar{A}_{ct+1} + \beta_{45}\bar{K}_{ct-1} + \beta_{46}\bar{K}_{ct+1} + \beta_{47}P_{Ct} + \beta_{48}P_{At} + \beta_{49}P_{Kt} + \bar{u}_{4ct} \quad (3.10)$$

$$\bar{A}_{ct} = \alpha_{5c} + \beta_{50} + \beta_{51}\bar{A}_{ct-1} + \beta_{52}\bar{A}_{ct+1} + \beta_{53}\bar{C}_{ct-1} + \beta_{54}\bar{C}_{ct+1} + \beta_{55}\bar{K}_{ct-1} + \beta_{56}\bar{K}_{ct+1} + \beta_{57}P_{At} + \beta_{58}P_{Ct} + \beta_{59}P_{Kt} + \bar{u}_{5ct} \quad (3.11)$$

$$\bar{K}_{ct} = \alpha_{6c} + \beta_{60} + \beta_{61}\bar{K}_{ct-1} + \beta_{62}\bar{K}_{ct+1} + \beta_{63}\bar{C}_{ct-1} + \beta_{64}\bar{C}_{ct+1} + \beta_{65}\bar{A}_{ct-1} + \beta_{66}\bar{A}_{ct+1} + \beta_{67}P_{Kt} + \beta_{68}P_{Ct} + \beta_{69}P_{At} + \bar{u}_{6ct} \quad (3.12)$$

Because the parameters in these equations are non-linear functions of the parameters in equations (3.10) - (3.12), we don't have prior expectations for their signs. Instead, we focus on the long-run demand elasticities.

The semi-reduced system is estimated by using iterated seemingly unrelated regression (ITSUR) method. The model coefficients are reported on Table 3.3. The long-run price and income elasticities calculated at the sample mean are shown on Table 3.4. The long-run own price elasticities are negative for all three goods. Cigarette and coffee have inelastic demands while alcohol demand is elastic. Bask and Melkersson (2004) also found that alcohol demand is elastic in the long-run. An explanation for this might be that most alcoholic beverage drinkers are just social drinkers. The income elasticity is positive and less than one for all three goods.

Regarding cross-price elasticities, only the cross-price elasticity of alcohol with respect to cigarette price, and the cross-price elasticity of coffee with respect to cigarette price are significant. The positive cross-price elasticities with respect to the cigarette price suggests that as the cigarette price increases people compensate reduced cigarette consumption with increased alcohol and coffee consumption.

Because the cross-price elasticity does not take into account the price sensitivity of the good whose price has been changed, Morishima elasticities of substitution are also calculated for the long-run. The elasticity of substitution measures how the relative consumption of two goods changes along the indifference curve when the relative prices change. Morishima elasticity of substitution is calculated using the formula:

$$\sigma_{ij}^{M} = \frac{\partial \ln (x_i^h / x_j^h)}{\partial \ln (p_j^h / p_i^h)} = \varepsilon_{ij}^h - \varepsilon_{jj}^h \tag{3.13}$$

where ε_{jj}^h and ε_{ij}^h are Hicksian own and cross price elasticities.

Hicksian price elasticities are derived as $\varepsilon_{ij=}^{h}\varepsilon_{ij}^{m} + s_j\varepsilon_{iy}$ where ε_{jj}^{m} is Marshallian cross-price elasticity, ε_{iy} is income elasticity and s_j is budget share of good j.

Morishima elasticiticies of substitution point to significant compensating behavior. All the Morishima elasticities of substitution are positive and significant. Except σ_{AK}, all the Morishima elasticities of substitution are greater than one. This suggests that cigarette, alcohol and coffee substitute each other along the indifference curve when the relative prices change. As the relative price of alcohol increases, the share of both cigarette and coffee consumptions relative to alcohol consumption increase suggesting that the consumer compensates reduced alcohol consumption with other addictive goods. Similar compensating behaviors apply to coffee and cigarette consumptions too.

3.6. Concluding Remarks

This study uses a pseudo-panel data approach to analyze the relationship between cigarettes, alcohol and coffee consumption within the rational addiction framework. The specification that we use is very general and nests several different behaviors and accounts for possible relationships among the three addictive goods.

We found that cigarette and coffee consumptions are consistent with rational addiction whereas alcohol consumption is not (i.e., in the alcohol demand equation lag and lead consumptions have negative coefficients). If there are inventory effects, this might be the reason why alcohol demand does not fit the theoretical model so well. In the previous chapter

when we replaced “overall alcohol expenditures” with “restaurant alcohol expenditures”, (restaurant) alcohol demand became consistent with rational addiction which reinforces our belief that in the current study the inconsistency of alcohol demand with the rational addiction model is due to inventory effects observed in quarterly alcohol expenditures.

The structural model does not suggest any significant reinforcement effect between coffee and cigarette consumption. However this does not rule out the possibility that coffee and cigarette consumption might reinforce each other for some subpopulations. On the other hand, in the semi-reduced system, the cross-price elasticity of coffee demand with respect to cigarette price is positive and significant suggesting that coffee substitutes for cigarettes when cigarette prices increase.

Morishima elasticiticies of substitution point to significant compensating behavior (i.e., cigarette, alcohol and coffee substitute each other along the indifference curve when the relative prices change). As the relative price of alcohol increases, the share of both cigarette and coffee consumptions relative to alcohol consumption increase suggesting that the consumer compensates reduced alcohol consumption with other addictive goods. Coffee and cigarette consumptions provide similar compensating behaviors. When relative price of cigarettes (alcohol) increase, consumers substitute cigarettes (alcohol) with alcohol (cigarettes). Our findings are consistent with Picone et al.(2004) who claim that alcohol and cigarettes are gross substitutes in price although they are complements in consumption for social drinkers. They explain positive cross-price responses with compensation and income effects. When there is a permanent increase in relative prices, addicts cut the consumption of a harmful addictive substance, and substitute it with another addictive substance to

compensate for the resulting stress. Moreover, when consumption of an addictive substance decreases due to a price increase, consumption of other addictive substances are likely to increase due to a positive income effect.

Although cigarette taxation has been cited as one of the most effective public health tools for cigarette control, the empirical results suggest that increasing cigarette prices might increase alcohol consumption (i.e., the cross-price elasticity of alcohol with respect to cigarette price is positive and significant in the semi-reduced system). Because of compensating behaviors of addicts, taxes might result in increases in the consumption of other addictive goods.

There are other studies that find evidence of addiction displacement. Using both qualitative and quantitative data, Skog (2006) examines if the decline in the Norwegian alcohol consumption during the nineteenth century is related to the growth of coffee culture as a substitute. He claims that coffee filled a cultural 'niche' created by the restrictive Norwegian alcohol policy (i.e., decreased availability and increased taxes) in the nineteenth century. He concludes that the decline in alcohol consumption was, in part, as a result of coffee substituting alcohol as an alternative 'new' beverage for all social classes.

Reich et al. (2008) investigate coffee and cigarette use among recovering alcoholics that participate in Alcoholics Anonymous (AA) meetings in 2007 in Nashville. They find that cigarette and coffee consumption among AA members is higher compared to the general U.S. population. Most recovering alcoholics explain that they consume coffee for its stimulatory effects (i.e., feeling better, higher concentration, more alertness), and they

consume cigarettes for its reduction of negative feelings (i.e., depression, anxiety and irritability).

Many studies support that kicking a habit becomes much easier when addicts form a new replacement habit. If compensating behaviors can be channeled toward harmless addictive substances such as caffeine or smokeless tobacco (e.g., Rodu and Cole, 2009 on smokeless tobacco consumption), the unintended consequences of increasing cigarette prices in the form of increased alcohol consumption can be avoided.

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Tables

Table 3.1. Cigarette, Alcohol and Coffee Demands Estimated Separately

Cigarettes			***Alcohol***			***Coffee***		
Constant	-7.416***	(2.269)	Constant	148.287**	(60.688)	Constant	1.533**	(0.603)
C_{t-1}	0.109**	(0.049)	A_{t-1}	-0.085**	(0.043)	K_{t-1}	0.105**	(0.053)
C_{t+1}	0.104**	(0.051)	A_{t+1}	-0.104***	(0.039)	K_{t+1}	0.103*	(0.054)
A_{t-1}	0.001	(0.002)	C_{t-1}	0.051	(1.130)	C_{t-1}	0.014	(0.013)
A_t	0.004	(0.002)	C_t	2.392**	(1.163)	C_t	0.003	(0.014)
A_{t+1}	0.002	(0.002)	C_{t+1}	0.274	(1.010)	C_{t+1}	-0.005	(0.013)
K_{t-1}	0.083	(0.195)	K_{t-1}	0.804	(4.313)	A_{t-1}	-0.0001	(0.001)
K_t	0.022	(0.203)	K_t	6.955	(4.578)	A_t	0.001	(0.001)
K_{t+1}	0.058	(0.190)	K_{t+1}	-0.955	(4.353)	A_{t+1}	-0.0001	(0.001)
P_{Ct}	-0.062	(0.089)	P_{At}	-61.551***	(7.113)	P_{Kt}	-0.038**	(0.019)
I	-0.0002	(0.002)	I	0.254***	(0.043)	I	0.001***	(0.0005)
fam. size	0.328***	(0.087)	fam. size	6.726***	(1.872)	fam. size	0.021	(0.020)
white	0.778**	(0.355)	white	37.363***	(7.411)	white	0.117	(0.086)
college	-0.326	(0.327)	college	7.640	(7.469)	college	0.073	(0.086)
adj. R^2	0.67		*adj.* R^2	0.52		*adj.* R^2	0.43	

Notes: Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, ** denotes significance at 5%, * denotes significance at 10%. The coefficients on cohort dummies are not reported to save space.

Table 3.2. Long-run Elasticities:

	Separate Demand Equations	
ε_{CC}	-0.297	(0.376)
ε_{AA}	-1.341***	(0.204)
ε_{KK}	-0.494**	(0.219)
ε_{CA}	-0.313**	(0.158)
ε_{CK}	-0.035	(0.045)
ε_{AC}	-0.026	(0.043)
ε_{AK}	-0.032	(0.034)
ε_{KC}	-0.017	(0.041)
ε_{KA}	-0.103	(0.155)
ε_{CI}	0.096	(0.080)
ε_{AI}	0.409***	(0.057)
ε_{KI}	0.350***	(0.078)
Morishima elasticities of substitution		
σ_{CA}	1.027***	(0.218)
σ_{CK}	0.459**	(0.205)
σ_{AC}	0.271	(0.341)
σ_{AK}	0.463**	(0.211)
σ_{KC}	0.280	(0.357)
σ_{KA}	1.238***	(0.242)

Notes: Elasticities calculated at sample means. Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%.

Table 3.3. Semi-reduced System of Cigarette, Alcohol and Coffee Demands Estimated Using ITSUR

Cigarettes			***Alcohol***			***Coffee***		
Constant	-6.870***	(2.294)	Constant	80.518	(61.996)	Constant	0.972	(0.622)
C_{t-1}	0.107**	(0.049)	A_{t-1}	-0.086**	(0.043)	K_{t-1}	0.101*	(0.053)
C_{t+1}	0.105**	(0.051)	A_{t+1}	-0.098**	(0.039)	K_{t+1}	0.100*	(0.054)
A_{t-1}	0.0004	(0.002)	C_{t-1}	1.027	(1.122)	C_{t-1}	0.023*	(0.013)
A_{t+1}	0.002	(0.002)	C_{t+1}	0.735	(1.005)	C_{t+1}	-0.002	(0.013)
K_{t-1}	0.084	(0.196)	K_{t-1}	1.175	(4.274)	A_{t-1}	-0.0002	(0.001)
K_{t+1}	0.094	(0.190)	K_{t+1}	-0.437	(4.319)	A_{t+1}	-0.0002	(0.0005)
P_{Ct}	-0.149	(0.108)	P_{At}	-72.41***	(8.556)	P_{Kt}	-0.070***	(0.022)
P_{At}	-0.054	(0.377)	P_{Ct}	7.494***	(2.458)	P_{Ct}	0.073***	(0.027)
P_{Kt}	0.153	(0.093)	P_{Kt}	-1.597	(2.291)	P_{At}	-0.042	(0.095)
rincome	0.0004	(0.002)	rincome	0.267***	(0.040)	rincome	0.002***	(0.0005)
fam. size	0.357***	(0.088)	fam. size	5.532***	(1.923)	fam. size	0.003	(0.022)
white	0.657*	(0.370)	white	31.046***	(8.176)	white	0.047	(0.092)
college	-0.341	(0.326)	college	6.647	(7.267)	college	0.074	(0.086)
adj. R^2	0.67		adj. R^2	0.53		adj. R^2	0.44	

Notes: Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, ** denotes significance at 5%, * denotes significance at 10%. The coefficients on cohort dummies are not reported to save space.

Table 3.4. Long-run Elasticities: Semi-reduced System

ε_{CC}	-0.552	(0.455)
ε_{AA}	-1.557***	(0.246)
ε_{KK}	-0.830***	(0.237)
ε_{CA}	-0.180	(0.335)
ε_{CK}	0.474	(0.289)
ε_{AC}	0.839***	(0.314)
ε_{AK}	-0.117	(0.206)
ε_{KC}	1.136***	(0.402)
ε_{KA}	-0.050	(0.315)
ε_{CI}	0.083	(0.080)
ε_{AI}	0.409***	(0.056)
ε_{KI}	0.348***	(0.078)
Morishima elasticities of substitution		
σ_{CA}	1.377***	(0.366)
σ_{CK}	1.304***	(0.360)
σ_{AC}	1.391***	(0.494)
σ_{AK}	0.713**	(0.300)
σ_{KC}	1.688***	(0.565)
σ_{KA}	1.508***	(0.394)

Notes: Elasticities calculated at sample means. Bootstrapped standard errors (1000 reps.) are reported in parenthesis. *** denotes significance at 1%, **denotes significance at 5%, * denotes significance at 10%.

Conclusion

If cigarette consumption affects alcohol consumption (and vice versa), the information about their relation may allow a better coordination of the public policies. In this dissertation, three essays are presented to investigate the relation between cigarette and alcohol consumption employing household level data in a rational addiction framework.

In the first essay, the relation between cigarette and alcohol consumption is investigated using two different household level data sets: Interview and Diary data (U.S. Bureau of Labor Statistics, Consumer Expenditure Survey). The different formats of the two data sets (i.e., rotating panel versus repeated cross-section) require the employment of two different econometric methods to estimate the dynamic demand models. Within-groups two-step GMM method (Bover and Arellano, 1997) is used for the Interview data; while for the Diary data, a pseudo-panel data approach is employed. Compared to Interview data results, the Diary data results overall conform better to the rational addiction model. It is argued that, in the Interview data, memory lapses would cause underreporting or over-reporting or simplification and/or modification of answers in a socially desirable direction. If different groups have different recall abilities, this can bias results. Diary data results are more reliable since Diary data are not likely to suffer from recall bias. Results based on Diary data show that cigarette (alcohol) consumption increases the marginal utility from alcohol (cigarette) consumption. On the other hand, long-run cross-price elasticities derived from the semi-reduced demand system indicate that alcohol is a substitute for cigarettes. Overall pseudo-panel results obtained from using Diary data are very encouraging. While many applied

studies of rational addiction model fail to find realistic discount rates, in this study the discount rates estimated for cigarette demand seem plausible. It is pointed out that the pseudo-panel data approach has many advantages, not only because it allows one to estimate dynamic models of individual behavior using cross-sectional data, but it also avoids econometric difficulties due to measurement error, censoring and attrition bias.

The second essay investigates how smoking bans at restaurants affect restaurant alcohol consumption using Diary data and pseudo-panel approach. Rather than analyzing how "overall alcohol consumption" is affected by smoking bans, the focus is on how "restaurant alcohol consumption" is affected by smoking bans at restaurants. Empirical results indicate useful public policy implications. Restaurant smoking bans decrease smoking, but they increase restaurant alcohol consumption. On the other hand, imposing lower blood alcohol concentration limits for drivers decreases both alcohol and cigarette consumption.

The third essay generalizes rational addiction model to include three addictive goods: cigarettes, alcohol and coffee. Cigarettes and coffee demands fit well with the rational addiction model, but alcohol demand does not. Although cigarette taxation has been cited as an effective public policy tool for cigarette control, our results reveal that rising cigarette prices might increase alcohol consumption. Long-run cross-price elasticities and the Morishima elasticities of substitution indicate that when relative prices change, consumers substitute addictive goods with other addictive goods due to compensation and income effects. It is argued that, if compensating behaviors can be channeled toward harmless addictive substances such as caffeine or smokeless tobacco the unintended consequences of increasing cigarette prices in the form of increased alcohol consumption can be avoided.

APPENDICES

Appendix A:Explicit Expressions of the Parameters in Equations 1.4 and 1.5

$$\beta_{10} = -\frac{u_C + \beta u_S}{(u_{CC} + \beta u_{SS})} \qquad \beta_{11} = -\frac{u_{CS}}{(u_{CC} + \beta u_{SS})} > 0 \qquad \beta_{12} = -\frac{\beta u_{CS}}{(u_{CC} + \beta u_{SS})} > 0$$

$$\beta_{13} = -\frac{u_{CD}}{(u_{CC} + \beta u_{SS})} \qquad \beta_{14} = -\frac{u_{CA} + \beta u_{SD}}{(u_{CC} + \beta u_{SS})} \qquad \beta_{15} = -\frac{\beta u_{AS}}{(u_{CC} + \beta u_{SS})}$$

$$\beta_{16} = \frac{\lambda}{(u_{CC} + \beta u_{SS})} < 0$$

$$\beta_{20} = -\frac{u_A + \beta u_D}{(u_{AA} + \beta u_{DD})} \qquad \beta_{21} = -\frac{u_{AD}}{(u_{AA} + \beta u_{DD})} > 0 \qquad \beta_{22} = -\frac{\beta u_{AD}}{(u_{AA} + \beta u_{DD})} > 0$$

$$\beta_{23} = -\frac{u_{AS}}{(u_{AA} + \beta u_{DD})} \qquad \beta_{24} = -\frac{u_{CA} + \beta u_{SD}}{(u_{AA} + \beta u_{DD})} \qquad \beta_{25} = -\frac{\beta u_{CD}}{(u_{AA} + \beta u_{DD})}$$

$$\beta_{26} = \frac{\lambda}{(u_{AA} + \beta u_{DD})} < 0$$

where λ is the marginal utility of wealth, u_{ij} are parameters carrying the sign of their respective derivatives (e.g., $u_{CC} < 0$ because $U_{CC} < 0$).

Appendix B: Calculation of Lewbel Price Indices for Alcoholic Beverages

Lewbel price indices allow heterogeneity in preferences within a given bundle of goods. Within bundle Cobb Douglas preferences are assumed, while among different bundles any specification is allowed. See Lewbel(1989) for details. Following Lewbel (1989) and Hoderlein and Mihaleva (2008), we construct Lewbel price indices as:

$$v_i = \frac{1}{k_i} \prod_{j=1}^{n_i} \left(\frac{p_{ij}}{w_{ij}} \right)^{w_{ij}}$$

where w_{ij} is the household's budget share of good j in group i. k_i is a scaling factor with $k_i = \prod_{j=1}^{n_i} \overline{w}_{ij}^{-\overline{w}_{ij}}$ and $\overline{w}_{ij}$ is the budget share of the reference household.

Let $p_{ij} = P_i$ where P_i is the price index for group i which is set to 1 in the first time period. Because there are zero expenditures for some subcategories, Lewbel price index cannot be used in levels (i.e., a number divided by zero is undefined). In the empirical analysis, Hoderlein and Mihaleva(2008) used log prices instead of prices in levels using the result that $lim \log_{x \to 0} x \log(x) = 0$. In our economic model, prices are in levels, so we first took the log of the Lewbel price index and then took the anti-log of it to obtain price indices.

In the current study, zero alcohol consumption might be due to so many different reasons such as quiting, abstention, corner solution and infrequency of purchase. For non-consumers, the Lewbel price index is assigned to be equal to 1 which means if the consumption took place, the expenditure shares would have been identical to that of reference household. To determine the expenditure shares of the reference household, we took the average of the expenditure shares for each consumer unit in the whole sample in the whole sample period.

Appendix C: Litterman's Method for Temporal Disaggregation of Time Series Data

Assume that observations of a variable are available only on an annual basis, but we need that variable's quarterly values. "Interpolation refers to the estimation of unobserved values of a stock variable whose actual values are observed less frequently" (Litterman 1983, p.169). Standard regression analysis can be employed to interpolate annual series using a related quarterly series. Assume that the quarterly values, y*****, have a linear relation with p observed quarterly variables:

$$y_{t,i}^{*} = \beta_1 x_{t,i}^{1*} + \beta_2 x_{t,i}^{2*} + \cdots + \beta_p x_{t,i}^{p*} + u_{t,i}^{*}$$

where $u_{t,i}^{*} = u_{t,i-1}^{*} + \epsilon_{t,i}^{*}$ and $\epsilon_{t,i}^{*} = \alpha\epsilon_{t,i-1}^{*} + e_{t,i}^{*}$ for quarter i of year t. The 4Tx1 vector $U^{*} = (u_{1,1}^{*} u_{1,2}^{*} \ldots u_{T,4}^{*})$ has covariance matrix V^{*}.

$$Y = BY^{*}$$

where $Y = (y_1 y_2 \ldots y_T)'$ be the Tx1 vector of annual observations, $Y^{*} = (y_{1,1}^{*} y_{1,2}^{*} \ldots y_{T,4}^{*})'$ be the 4Tx1 vector of unobserved quarterly values, and

$$B = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & . & . & . & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & . & & & & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & & \cdot & & & & & \\ . & . & . & . & . & . & . & . & & & . & & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & & & & 0 & 0 & 0 & 1 \end{bmatrix}$$

Then the optimal unbiased estimator of Y^{*} is:

$$\hat{Y}^{*} = X^{*}\hat{\beta} + V^{*}B'(BV^{*}B')^{-1}\hat{U}$$

where

$$X^* = \begin{bmatrix} x_{1,1}^{1*} & x_{1,1}^{2*} & . & . & . & x_{1,1}^{p*} \\ x_{1,2}^{1*} & x_{1,2}^{2*} & . & . & . & x_{1,2}^{p*} \\ . & . & & & & . \\ . & . & & & & . \\ x_{T,4}^{1*} & x_{T,4}^{2*} & . & . & . & x_{T,4}^{p*} \end{bmatrix}$$

$\hat{\beta} = [X'(BV^*B')^{-1}X]^{-1}X'(BV^*B')^{-1}Y$ is the generalized least squares estimate that results from a regression of Y on X, with X= BX* and $\widehat{U} = Y - X\widehat{\beta}$.

We make the estimation using Ecotrim program developed by Eurostat.

Appendix D: Derivation of Equations (3.4) - (3.6)

The quadratic utility function is:

$$U = \frac{1}{2}u_{CC}C_t^2 + \frac{1}{2}u_{AA}A_t^2 + \frac{1}{2}u_{KK}K_t^2 + \frac{1}{2}u_{NN}N_t^2 + \frac{1}{2}u_{SS}S_t^2 + \frac{1}{2}u_{DD}D_t^2 + \frac{1}{2}u_{LL}L_t^2$$
$$+u_{CA}C_tA_t + u_{CK}C_tK_t + u_{CS}C_tS_t + u_{CD}C_tD_t + u_{CL}C_tL_t + u_{AK}A_tK_t + u_{AS}A_tS_t$$
$$+ u_{AD}A_tD_t + u_{AL}A_tL_t + u_{KS}K_tS_t + u_{KD}K_tD_t + u_{KL}K_tL_t + u_{SD}S_tD_t + u_{SL}S_tL_t$$
$$+ u_{DL}D_tL_t + u_CC_t + u_AA_t + u_KK_t + u_NN_{it} + u_SS_{it} + u_DD_{it} + u_LL_{it}$$

u_{ij} are parameters carrying the sign of their respective derivatives (e.g., $u_{CC} < 0$ because $U_{CC} < 0$). We assume that $S_t = C_{t-1}$, $D_t = A_{t-1}$ and $L_t = K_{t-1}$.

$$\max L = \sum_{t=1}^{\infty} \beta^{t-1}\, U(C_t, A_t, K_t, C_{t-1}, A_{t-1}, K_{t-1}, N_t)$$
$$-\lambda(W - \textstyle\sum_{t=1}^{\infty} \beta^{t-1}\,(\, P_{Ct}C_t + P_{At}A_t + P_{Kt}K_t + N_t\,))$$

Derive the first order condition(FOC) with respect to C_t:

$$\frac{\partial L}{\partial C_t} = \frac{\partial U(C_t, A_t, K_t, C_{t-1}, A_{t-1}, K_{t-1}, N_t)}{\partial C_t} + \beta \frac{\partial U(C_{t+1}, A_{t+1}, K_{t+1}, C_t, A_t, K_t, N_{t+1})}{\partial C_t}$$
$$- \lambda P_{C_t}$$

$$= u_{CC}C_t + u_{CA}A_t + u_{CK}K_t + u_{CS}C_{t-1} + u_{CD}A_{t-1} + u_{CL}K_{t-1} + u_C + \beta(u_{SS}C_t$$

$$+u_{CS}C_{t+1} + u_{AS}A_{t+1} + u_{KS}K_{t+1} + u_{SD}A_t + u_{SL}K_t + u_S) - \lambda P_{Ct} = 0$$

Solving FOC for C_t:

$$C_t = \beta_{10} + \beta_{11} C_{t-1} + \beta_{12} C_{t+1} + \beta_{13} A_{t-1} + \beta_{14} A_t + \beta_{15} A_{t+1} + \beta_{16} K_{t-1} + \beta_{17} K_t + \beta_{18} K_{t+1} + \beta_{19} P_{Ct}$$

where

$$\beta_{10} = -\frac{u_C + \beta u_S}{(u_{CC} + \beta u_{SS})} \qquad \beta_{14} = -\frac{u_{CA} + \beta u_{SD}}{(u_{CC} + \beta u_{SS})} \qquad \beta_{18} = -\frac{\beta u_{KS}}{(u_{CC} + \beta u_{SS})}$$

$$\beta_{11} = -\frac{u_{CS}}{(u_{CC} + \beta u_{SS})} > 0 \qquad \beta_{15} = -\frac{\beta u_{AS}}{(u_{CC} + \beta u_{SS})} \qquad \beta_{19} = \frac{\lambda}{(u_{CC} + \beta u_{SS})} < 0$$

$$\beta_{12} = -\frac{\beta u_{CS}}{(u_{CC} + \beta u_{SS})} > 0 \qquad \beta_{16} = -\frac{u_{CL}}{(u_{CC} + \beta u_{SS})}$$

$$\beta_{13} = -\frac{u_{CD}}{(u_{CC} + \beta u_{SS})} \qquad \beta_{17} = -\frac{u_{CK} + \beta u_{SL}}{(u_{CC} + \beta u_{SS})}$$

Solving FOC , $\frac{\partial L}{\partial A_t} = 0$, for A_t:

$$A_t = \beta_{20} + \beta_{21} A_{t-1} + \beta_{22} A_{t+1} + \beta_{23} C_{t-1} + \beta_{24} C_t + \beta_{25} C_{t+1} + \beta_{26} K_{t-1} + \beta_{27} K_t + \beta_{28} K_{t+1} + \beta_{29} P_{At}$$

where

$$\beta_{20} = -\frac{u_A + \beta u_D}{(u_{AA} + \beta u_{DD})} \qquad \beta_{24} = -\frac{u_{CA} + \beta u_{SD}}{(u_{AA} + \beta u_{DD})} \qquad \beta_{27} = -\frac{u_{AK} + \beta u_{DL}}{(u_{AA} + \beta u_{DD})}$$

$$\beta_{21} = -\frac{u_{AD}}{(u_{AA} + \beta u_{DD})} > 0 \qquad \beta_{25} = -\frac{\beta u_{CD}}{(u_{AA} + \beta u_{DD})} \qquad \beta_{28} = -\frac{\beta u_{KD}}{(u_{AA} + \beta u_{DD})}$$

$$\beta_{22} = -\frac{\beta u_{AD}}{(u_{AA} + \beta u_{DD})} > 0 \qquad \beta_{26} = -\frac{u_{AL}}{(u_{AA} + \beta u_{DD})} \qquad \beta_{29} = \frac{\lambda}{(u_{AA} + \beta u_{DD})} < 0$$

$$\beta_{23} = -\frac{u_{AS}}{(u_{AA} + \beta u_{DD})}$$

Solving FOC , $\frac{\partial L}{\partial K_t} = 0$, for K_t:

$$K_t = \beta_{30} + \beta_{31} K_{t-1} + \beta_{32} K_{t+1} + \beta_{33} C_{t-1} + \beta_{34} C_t + \beta_{35} C_{t+1} + \beta_{36} A_{t-1} + \beta_{37} A_t + \beta_{38} A_{t+1} + \beta_{39} P_{Kt}$$

where

$$\beta_{30} = -\frac{u_K + \beta u_L}{(u_{KK} + \beta u_{LL})} \qquad \beta_{34} = -\frac{u_{CK} + \beta u_{SL}}{(u_{KK} + \beta u_{LL})} \qquad \beta_{38} = -\frac{\beta u_{AL}}{(u_{KK} + \beta u_{LL})}$$

$$\beta_{31} = -\frac{u_{KL}}{(u_{KK} + \beta u_{LL})} > 0 \qquad \beta_{35} = -\frac{\beta u_{CL}}{(u_{KK} + \beta u_{LL})} \qquad \beta_{39} = \frac{\lambda}{(u_{KK} + \beta u_{LL})} < 0$$

$$\beta_{32} = -\frac{\beta u_{KL}}{(u_{KK} + \beta u_{LL})} > 0 \qquad \beta_{36} = -\frac{u_{KD}}{(u_{KK} + \beta u_{LL})}$$

$$\beta_{33} = -\frac{u_{KS}}{(u_{KK} + \beta u_{LL})} \qquad \beta_{37} = -\frac{u_{AK} + \beta u_{DL}}{(u_{KK} + \beta u_{LL})}$$

For k=1,2,3: $\beta_{k2} = \beta * \beta_{k1}$ or $\beta_{k1} = (1 + r)\beta_{k2}$ since $\beta = \frac{1}{(1+r)}$ with r being discount rate.