Understanding Forward-Looking Behavior using Dynamic Discrete Choice and Rational Addiction Model:
Application to California Cigarette Tax Increase

Hwikook Choe*

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Abstract

Consumer's forward-looking behavior can create change in current purchase and consumption in response to the change in expectation on future price. Using cigarette tax increase in California as exogenous variation, I found peak in purchase right before the actual price increase and plunge after the increase. Using dynamic discrete choice model with rational addiction and stockpiling, I found that change in the timing of tax increase announcement can incur change in consumer's steady state of consumption in the long run.

Keywords: dynamic discrete choice model; rational addiction; consumer inventory behavior; cigarettes;

*hkchoe@uchicago.edu

1 Introduction

Consumers make their purchase and consumption choice based on their preferences. One of key factors that affect consumer preference is price. In general, by the Law of Demand, an increase in price decreases the quantity demanded for the product. An interesting aspect of the price is that not only the current price but also the expected future price can affect consumer choice. If people expect that the future price would increase, then they increase the quantity demanded before the actual price increase. If the good is storable, then consumer might even purchase more to increase inventory.

If the good is addictive, the purchasing behavior in response to price increase expectation and subsequent stockpiling might be different compared to non-addictive goods. Key insights about rational addiction are reinforcement, an increase in current consumption leads to the increase in future consumption, and tolerance, an increase in current consumption leads to less future utility given the amount of consumption (Becker and Murphy 1988). Thus, if a good is addictive, the degree of stockpiling might be different. On the one hand, because of considering reinforcement, consumer might reduce the consumption in order to reduce addiction level and stockpile less. On the other hand, because of considering tolerance, consumer might stockpile more not to reduce the consumption.

Using the consumer panel data from Nielsen IQ, I studied how consumer's purchase and consumption behavior changes with respect to expected future price increase. Specifically, by using California Proposition 56, which announced cigarette tax increase from $ 0.87 per pack to $2.87 per pack in November 7th, 2016 and went into effect in April 1st, 2017, as treatment, I studied how smokers changed their purchase and consumption behavior in response to tax increase announcement and actual tax increase.

In order to investigate how consumer's purchased quantity changes as the future price changes, I used synthetic control method. The results show that consumer increased their purchase amount right before the actual price increase, in order to increase stock. After the actual price increase, consumers purchase less and consume their stock.

Since consumer's stockpiling behavior in response to expected future price increase alleviates the abrupt change in consumption, the steady state in the long run might be different if the time gap between announcement date and effective date was different, because of the addictive nature of cigarettes. By using the dynamic discrete choice model, I found out that the steady state in the long run can be changed by the time gap between the tax increase announcement and actual tax increase.

Previous literature dealing relevant idea are discussed in section 2. Background information about cigarette tax increase in California is explained in section 3. Data that I used for the analysis is explained in section 4. The reduced form analysis for estimating the announcement effect is explained in section 5. The structural form analysis for estimating the effect of announcement-effect time gap and counterfactual analysis are suggested in section 6. Further discussions and conclusion are discussed in section 7.

2 Literature Review

2.1 Synthetic Control

Synthetic control method (Abadie and Gardeazabal 2003, Abadie, Diamond, and Hainmueller 2010) is one of the most widely applied methods in empirical research in economics and other disciplines. In order to find the treatment effect in response to an exogenous variation, a researcher should find the counterfactual data where the treated group are not treated at the same time period. However, this hypothetical data cannot exist in real world, since an observation cannot be treated and untreated at the same time. Thus, the key challenge is to estimate the counterfactual data.

Synthetic control is one of the methods that estimate the counterfactual data, by synthesizing control groups (donor pool) to resembles the pattern of the treated group in the pre-treatment period. Thus, the comparison between the treated group and synthesized group after the treatment can be interpreted as the treatment effect.

I used synthetic control method in order to find the effect of tax increase announcement and actual tax increase on cigarette sales in California.

2.2 Dynamic Discrete Choice Model

Dynamic discrete choice model was first used for the study of optimal bus engine replacement decision (Rust 1987). This insight of the model is that the current period state variable could affect the choice in the next period. Thus, when an agent determines the choice variable in the current period, the agent also should consider the effect of choice in the future. This inter-dependency of time periods leads to the dynamic model. The strategy to solve the model and estimate the underlying demand parameter is nested fixed-point algorithm (NFXP).

For cigarette smokers, the time-dependency exists. One scenario is that the cigarette consumption in current period changes the addiction level, and the changed addiction level changes the utility of cigarette consumption in the future period. Another scenario is that by consuming one more pack of cigarette in current period, the inventory of cigarettes is decreased by one pack. Thus, this consumption will leads to an increased probability to purchase more cigarettes in the future. Therefore, I used dynamic discrete choice model to analyze the smoker's behavior.

2.3 Rational Addiction

Studied by Becker and Murphy (Becker and Murphy 1988), addiction was understood as rational behavior. The rational addiction theory suggests that addiction is the result of rational choice, not the result of irrational and emotional behavior. By calculating the effect of addiction in the future, rational agent determines the consumption in the current period which might affect the addiction level in the future.

2.4 Consumer Inventory Behavior

Studied by Hendel and Nevo (Hendel and Nevo 2006), considering consumer inventory behavior is crucial when understanding the consumer choice. Without implementing the inventory in the model, whereas the consumers set inventory in the real world, the price elasticities estimates might be biased. Specifically, the own-price elasticities are overestimated, cross-price elasticities are underestimated, and substitutions to the no-purchase are overestimated.

Since cigarettes can be stocked and the change in the inventory in response to the tax increase is the key variable of interest in my model, I applied consumer inventory behavior.

3 Backgrounds

In November 8, 2016, voters passed California Proposition 56, the Tobacco Tax Increase Initiative. It contains to increase the tax on cigarette from $0.87 per pack to $2.87 per pack, starting from April 1, 2017.

4 Data

I used consumer panel data provided by Nielsen IQ. The time period that I used was 1/1/2016 - 12/31/2017. Number of households in California that appear in both years and ever purchased a pack of cigarette during the sample period is 446. I classified households into four groups of smokers (non-smokers, light smokers, average smokers, and heavy smokers) based on the quantity consumed during the pre-treatment period. Non-smokers are households who did not purchase any cigarette, and other smoker groups are divided to have equal proportion based on weekly consumption.

5 Reduced Form Analysis

By using synthetic control, I estimated the effect of cigarette tax increase announcement and actual increase on people's purchasing behavior. Specifically, By aggregating the individual purchase in state level, I constructed synthetic California to compare with real California and estimated the effect of tax increase announcement and actual increase. Let Y_{jt} be the cigarette sales per capita in state j and in week t. I assigned $j = 1$ to California, and $j = 2, ..., 48$ to other states, where Alaska is not included, or "donor pool". In order to construct synthetic California that resembles the sales pattern of real California during the pre-treatment period, where $t = 0, ..., T_0$, I calculated appropriate weights on donor pool by minimizing the following equation.

$$\min_{\omega} \sum_{t=0}^{T_0} \left(Y_{1t} - \sum_{j=2}^{48} \omega_j Y_{jt} \right)^2 \text{ s.t. } \omega_j \geq 0 \text{ and } \sum_{j=2}^{48} \omega_j = 1 \tag{1}$$

By the construction of synthetic control, the difference between actual California and synthetic California can be interpreted as the effect of treatment on the variables of interest.

The result of weight is as follows.

state	weight	state	weight	state	weight
CO	0.015	MA	0.037	NY	0.405
CT	0.137	ME	0.022	OH	0.002
FL	0.062	MS	0.045	RI	0.090
IA	0.038	MT	0.005	SD	0.053
IN	0.015	ND	0.011	UT	0.063

Table 1: Weight for Synthetic California

By using the above weights, the per capita sales of cigarettes on a weekly basis for real California and synthetic California is as follows. The blue line is the sales for California, and the orange line is the sales for synthetic California. After the tax increase announcement (November 8, 2016, marked as red line), consumers in California decreased their purchases until the time right before the effective date. Right before the effective date, the sales

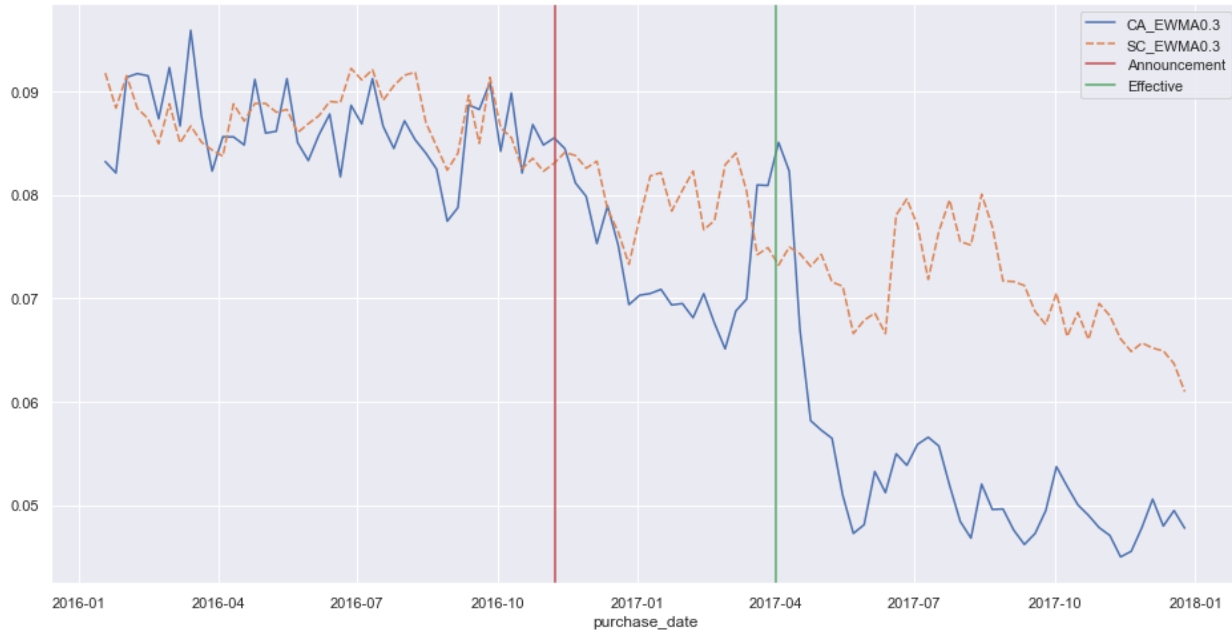

Figure 1: weekly cigarette sales per capita

skyrocketed. After the effective date, the sales returned to the decreased amount, much lower than the synthetic California.

The graph above shows that people changes their purchases after the tax increase announcement before the actual tax increase. In reaction to the announcement, people tries to reduce the smoking amount to alleviate the burden of increased future price. At the time of effective date, people increased purchase only for a short period to stockpile.

6 Structural Form Analysis

By building a structural model with underlying demand parameters that are invariant to policy change, it is possible to do counterfactual analysis. In this paper, I would change the time gap between tax increase announcement date and effective date and inspect how the time gap affects steady state consumption in the long run. In order to do so, I build dynamic discrete choice model with rational addiction and consumer inventory behavior.

6.1 Period Utility

Consumer's period utility function is composed of three parts: consumption utility, purchase utility, and inventory cost.

$$U(c_{it}, d_{it}, s_{it}; \theta_i) = u_c(c_{it}, a_{it}; \alpha_i) + u_p(d_{it}, P_t; \gamma_i, \xi_i) - C(I_{it}; h_i) \tag{2}$$

Consumers make decision on quantity consumed, c_{it}, and which products to buy and how much to buy, d_{it}. In here, $d_{itjq} = 1$ if product j is purchased by the amount of q, and $d_{it} = \{d_{itjq}\}_{jq}$ is a vector, such that $\sum_{jq} d_{itjq} = 1$.

Period consumption utility is as follows.

$$u_c\left(c_{it}, a_{it}; \alpha_i\right) = \alpha_{i0} I\left\{c_{it} = 0\right\} + \alpha_{i1} c_{it} + \alpha_{i2} c_{it}^2 + \alpha_{i3} a_{it} + \alpha_{i4} a_{it}^2 + \alpha_{i5} a_{it} c_{it} \tag{3}$$

The variable a_{it} represents the addiction level of individual i at time t, and it is a stock variable. The quadratic form is flexible so that it could capture the "adjacent complementarity", which could be the reinforcement of past stock that changes the current marginal utility. The formation of addiction stock is as follows.

$$a_{i,t+1} = (1 - \delta_i) a_{it} + c_{it} \tag{4}$$

where $0 \leq \delta_i \leq 1$ is depreciation rate.

Period purchase utility is as follows.

$$u_p\left(d_{it}, P_t; \gamma_i, \xi_i\right) = \sum_{j,q} d_{itjq}\left(\gamma_i p_{tjq} q_{itj} + \xi_{ijq} + \varepsilon_{itjq}\right) \tag{5}$$

In the subscript, j represents the product tier and q represents the quantity. q_{itj} is the purchase quantity, p_{tjq} is the price, and γ_i is the parameter for price sensitivity. ξ_{ijq} is the fixed-effects for products, and ε_{itjq} is the unobserved shock that is distributed i.i.d. extreme value.

Inventory cost is as follows.

$$C(I_{it}; h_i) = h_i I_{it} \tag{6}$$

The inventory I_{it} is also a stock variable, and it is formed by the following law of motion

$$I_{i,t+1} = I_{it} + \sum_{j,q} d_{itjq} q_{itj} - c_{it} \tag{7}$$

6.2 Price Expectation

Following previous literature on price process (Erdem, Imai, and Keane 2003), I assume price process without the regime change follows 1st order Markov process. Furthermore, I assume consumers make expectation on price the same way. The price process during normal phase is as follows.

$$\begin{pmatrix} \ln(P_{t0}) \\ \ln(P_{t1}) \end{pmatrix} = \begin{pmatrix} \gamma_{10} + \gamma_{20} \ln(P_{t-1,0}) + \gamma_{30} \ln(P_{t-1,1}) \\ \gamma_{11} + \gamma_{11} \ln(P_{t-1,1}) + \gamma_{31} \ln(P_{t-1,0}) \end{pmatrix} + \begin{pmatrix} \nu_{t0} \\ \nu_{t1} \end{pmatrix} \tag{8}$$

6.3 Dynamic Decision Problem

I divided the whole periods into three phases. First phase is the period before the tax increase announcement. Second phase is the period after the announcement but before the actual enactment. Third phase is the period after the enactment. The dynamic decision in the third phase is as follows. I wrote it using value function form.

$$V_3(s_{it}) = \max_{c_{it}, d_{it}} \{U(c_{it}, d_{it}, s_{it}; \theta) + \beta \mathbb{E}[V_3(s_{i,t+1}) | s_{it}]\} \tag{9}$$

The decision problem at the starting moment of the second phase is as follows.

$$V_2(s_{iT}) = \max_{\{c_{it}, d_{it}\}} \sum_{t=T}^{T'} \{\beta^{t-T} \mathbb{E}[U(c_{it}, d_{it}, s_{it}; \theta)]\} + \beta^{(T'-T)} V_3(s_{iT'}) \tag{10}$$

The decision problem during the first phase is similar to that of the third phase. The reason is that during the first phase, the tax increase announcement was not made. Thus, consumers do not expect the price increase in the future. In other words, consumers expect the future price would follow the same price process as it was. Thus, the decision problem is as follows.

$$V_3(s_{it}) = \max_{c_{it},d_{it}} \{U(c_{it}, d_{it}, s_{it}; \theta) + \beta\mathbb{E}[V_3(s_{i,t+1})|s_{it}]\} \tag{11}$$

6.4 Result

Currently, I'm finding the underlying demand parameters using Maximum Likelihood Estimation (MLE). The idea is to find parameters that has the highest likelihood given the data. Since the model above has more than 20 parameters and the model is nested with inner loop and outer loop, it takes more than 3 minutes to perform single iteration using Nelder-Mead algorithm, on Google Colaboratory server.

The plan after getting the parameters is to do simulations by changing the tax increase policy. Specifically, by changing the time gap between tax increase announcement date and effective date, the counterfactual analysis can show that the time gap could impact on people's purchase and consumption behavior in equilibrium.

Suppose the increase in time gap makes people to adjust their consumption at a slower pace. It could be possible that by reducing the consumption at a slower pace, the addiction level would alleviate at a slower pace. It could imply that the optimal addiction level could be increased. On the other hand, suppose zero time gap between announcement date and effective date. It could make consumers to adjust their consumption abruptly, even 'cold turkey'. This abrupt change could result in sudden drop of addiction level, lowering the optimal addiction level compared to the previous case.

7 Discussions and Conclusion

By using the consumer panel data, I found that consumers change their current consumption level in reaction to change in expected future price. Although I aggregated the individual level data to state level in order to perform synthetic control, it is possible to perform synthetic difference-in-differences (SDID) ((Arkhangelsky et al. 2019)) for the individual level data.

The structural model helps to find underlying preference parameters that are invariant to policy change. Thus, it allows us to perform counterfactual analysis assuming hypothetical policy change. I will update the result after the optimal parameters are found.

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