Bottle Bills, Borders, and Fraudulent Redemption

Kramer and Newman drive to Michigan

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Abstract

Much literature has shown that a bottle bill creates incentives against littering and to a lesser extent promotes the recycling of beverage containers. The scope of such research has been limited however to purely looking at the choice between disposal methods within a single state or jurisdiction. This paper extends the analysis by looking at the impact of a bottle bill on the populations of two bordering states when container policies are asymmetric and households are mobile. Under certain cases, this asymmetry creates incentives for households to engage in illegal - fraudulent - bottle redemption. Using a model, I formally characterize households' behavior and, states' social welfare when accounting for the possibility of cross-border purchases and fraudulent redemptions. I then analyze the case of the Michigan Bottle Bill and the newly established Anti-fraud Act in the context of this model.

1 Introduction

Bottle bills have been implemented by a number of states for the primary purpose of reducing littered beverage containers and more recently to promote recycling efforts. Such policies typically establish a deposit and redemption system whereby the consumer pays the per container deposit at the time of purchase (remitted by the seller). The deposit is later refunded when the container is redeemed at a redemption facility via reverse vending machines (RVM's). RVM's are generally located at grocery retail locations. This paper seeks to characterize the behavior of households in two bordering states with asymmetric container policies. Specifically, I analyze the case when one state has a bottle bill and the other state does not. If households are mobile and enforcement is non-perfect, then households may choose to fraudulently redeem containers for which a deposit has not been paid. For this paper, I consider two types of fraudulent redemption. In-state fraud is defined as when households of the bottle bill state redeem containers purchased out-of-state. Out-of-state fraud is defined as when out-of-state households transport and redeem their out-of-state containers. How does this wrinkle affect the effectiveness and efficiency of bottle bills? Finally, I use the model and its results to make predictions on the case of Michigan and the Anti-fraud Act (enacted to combat fraudulent redemption). I argue that omitting these aspects constitutes a crucial oversight that generates greatly different results.

As previously mentioned, the first application of bottle bills was towards curbing litter. Since a majority of litter was composed of beverage containers, the usage of deposit-refund systems was seen as an effective method to both disincentivize littering but also address various potential negative externalities (eg. eyesore cost, waste processing, resource draw-down). Porter (1978) was one of the first papers that looked at bottle bills from an economic efficiency standpoint. Porter looked at five possible areas that a bottle bill would/could effect and analyzed their summed social welfare implications. His simple model was very much a cost-benefit analysis that included economic welfare considerations. Using estimated financial figures, Porter argued that bottle bills could be welfare improving when government's costs of implementation and household's private inconvenience costs were relatively low.

Dobbs (1991) approached the bottle bill from an optimal Pigouvian taxation standpoint. He highlighted the presence of externalities in all forms of disposal. First, littering imposes a negative externality that can be addressed by a disposal tax paid at the time of purchase (ie. a bottle deposit). Second, waste disposal also generates a negative externality exists because each additional unit of refuse consumed incurs greater cost by all of society.[1] This second externality is addressed by a user tax paid after the original purchase. Given the assumptions of his model, Dobbs showed that the optimal combination of Pigouvian taxes was was a deposit-refund policy. This was surprising since a negative externality is typically addressed via a tax. However, Dobbs' result indicated that the optimal user tax is actually a subsidy in the form of a bottle deposit. Eggert-Weichenrieder (2004) also looks at the optimal mechanism question. Their paper claims that deposit-refund systems are never optimal unless additional taxes are included to extract the added surplus gained by producers. This result centers on the assumption that producers have some market power and adjust prices in response to a bottle bill. More recently, most literature concerning bottle bills has centered on the recycling aspect. Fullerton, and Calcott and Walls have all written a number of papers on the effectiveness of bottle bill systems in affecting waste management. Viscusi et al (2009) is a recent paper that uses data from a national sample of 2500 households to look at how individual characteristics influence the likelihood to recycle water bottles. It is one of the first papers to actually do so. They found that responses to recycling and redemption were typically all or nothing choices. With no intervention, about 45% of households recycled 0/10 bottles and 25% recycled 10/10 bottles. Including a bottle deposit causes only 8% of households to recycle 0/10 bottles and 62% to recycle 10/10 bottles. The validity of these results should be taken with a grain of salt since there are a number of endogeneity issues.

The contribution of this paper is to inject the intra- and inter-state dynamic into the bottle bill analysis. As of now, fraudulent redemptions have been a subject limited to policy, law, and governmental studies. Michigan commissioned a report by Stutz-Gilbert (2000) to analyze and quantify the magnitude of fraudulent redemption in revenue terms only. The previous models of Porter, Dobbs, and Eggert-Weichenrieder all ignored this aspect of bottle bills. Their results on household behavior, optimality, and social welfare did not take into account the impact of having these additional dynamics. This paper addresses these crucial issues and creates a more dynamic and applicable model with which to judge bottle bills.

[1] Consider the impact of an additional article of refuse that needs to be picked up and then deposited into a landfill.

2 Background

In 1972, Oregon became the first state to enact legislation mandating a deposit policy on certain beverage containers. Since that time, ten other states including California and New York have enacted similar legislation which have come to be known colloquially as "bottle bills".[2] The format of the policy works as follows. A deposit is paid by consumers at the time of purchase in addition to the sale price. Typically, the amount of the deposit is either five cents or ten cents. The consumer can then return the empty containers to reverse vending machines (RVM's) located at most beverage retailers where they are refunded the amount of the deposit. The scope of the policies encompass a wide range of beverages - the majority being carbonated and alcoholic (excluding hard alcohol) beverages. The major types of containers are glass bottles, plastic bottles, and aluminum cans. Originally, one of the goals of bottle bill legislation was to promote greater uptake of refillable containers such as some glass bottles. The belief was that reusable refillable bottles would be less costly for bottling companies versus containers which required recycling and reformation. While the presence of bottle bills did result in increased usage of refillable bottles, the overall usage of refillable bottles as a whole has decreased greatly such that they comprised only 7% and 5% of all soft drink and beer containers as of 1990 (McCarthy 1993).

In the modern era, bottle bills have been hailed by lawmakers and environmentalists as both an anti-littering and pro-recycling tool. New York, which passed its bottle bill in 1983, saw a 70%-80% decrease in littered beverage containers and a 30% decrease in total litter (Final Report of the Temporary State Commission on Returnable Beverage Containers 1985). Additional reports such as A similar result was found in studies performed by the other states. The bottle bill also has a positive impact on recycling. An EPA sponsored study found that the nine bottle bill states (excluding California) accounted for approximately two-thirds of the nation's total glass recycling activity, even though they were only 18% of the population. When California is included, this figure went up to 80% (Aluminum Recycling 1991). The economic benefit of bottle bills is drawn primarily from the social welfare gains of reducing litter (an eyesore cost to the public) and increasing recycling (reducing the accumulation of solid waste in landfills). However, bottle bills also represent a source of revenue for the state

[2]The complete list of states is: California, Connecticut, Delaware, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Oregon, and Vermont

government. In particular, the ratio of deposits to refunds is greater than one such that not all containers (for which a deposit was paid) are returned for refund. In Michigan, the escheat or unclaimed funds are divided between retailers (25%) and the state government (75%). Estimated escheat in 1995 was $8.7 million (Michigan Bottle Bill 2000).

Fraudulent redemptions are officially defined as redeemed containers for which no deposit was paid. Notice that this does not preclude out-of-state individuals from redeeming containers within a bottle bill state. As previously mentioned, I consider in-state and out-of-state fraudulent redemptions. In-state fraud is no less of an issue than out-of-state fraud. For individuals and households, fraudulent redemption occurs on a relatively small scale. However, larger schemes do exist. For example, a joint project sponsored by the Michigan State Police, State Attorney General's Office, Dept. of Environmental Quality, and the Dept. of Treasury was able to apprehend two sophisticated fraudulent redemption operations in Ohio. "Operation Can Scam" estimated that the two can-smuggling rings sold millions of out-of-state containers to stores in Southeast Michigan (Bottle Bill Revisions 2008). The penalties for fraudulent redemption are fairly light. The updated penalties for Michigan state that the fraudulent redemption of 25 to 100 containers is a misdemeanor punishable by a maximum fine of $100. Repeated violations or fraudulent redemption of more than 100 containers is a misdemeanor punishable by at most 93 days of jail-time and/or a $500 fine. While larger rings are more noticeable and garner greater attention from law enforcement, the policing of individual households is virtually impossible. This model looks at the behavior of these un-policeable units.

3 Model

Consider a model of two bordering states, A and B, with state A having a bottle bill. Household i in state j, resides distance d_i (in miles) from the state border. Let $d_i \in [0, \bar{d}_j]$ where $\bar{d}_j$ is the furthest distance from the border in state j. For each state, households/populations are distributed according to the pdf's $h_j(d_i)$ for $j = \{A, B\}$. Let N_j denote the population size of state j. Utility for household i comes from consumption of three goods x, y, and G_j. I assume that the utility function $U(x, y, G)$ is continuous, strictly quasi-concave in goods x and y, and quasi-concave in G. Good x is a redeemable good. Good y is a composite bundle of non-redeemable goods y_i. Each household has income M. Lastly, G_j is a tax funded local (state) public good .[3]

Households purchase good x from a continuum of stores located at each d_i. The production function for good x is identical across stores and exhibits constant returns to scale. These two assumptions imply that the price of good x is equal across stores and states. Let p be the pre-tax price of good x, with an additional state-specific sales tax given by t_j.[4] Since state A has a bottle bill, there is an additional deposit τ that is paid by consumers and remitted by stores at the point of sale. The price paid by consumers on x is therefore $[(1+t_A)p+\tau]$ and $(1+t_B)p$ in states A and B. The price received by sellers is p in both states. Households in either state have the option of cross-border shopping for good x. For good y, I assume that it is a locale-specific good which cannot be cross-border shopped and make no assumptions on the price - p_j. Let s_j be the sales tax on purchases of good y. Denote the good x tax differential between states A and B by $\bar{t}$.

$$\bar{t} = t_A - t_B \tag{1}$$

Cross-border shopping and redeeming may require traveling which is costly. Let $C_i^T(\hat{d}_i)$ denote the utility cost of travel and $K_i^T(\hat{d}_i)$ denote the financial cost of travel, where $\hat{d}_i$ is the distance traveled by household i.

$$C_i^T(\hat{d}_i) = c_i^T \hat{d}_i \text{ and } K_i^T(\hat{d}_i) = k^T \hat{d}_i \tag{2}$$

The marginal utility cost of traveling another mile, c_i^T, is drawn from the distribution F^T. k^T, which can be interpreted as the per mile financial cost of driving (eg. fuel costs, car depreciation), is constant across households. Let I_j be an indicator function that equals one if the household cross-border shops. In this model, I assume that households make at most one trip.[5]

After consuming good x, it must disposed. There are three methods of disposal: littering,

[3] G_j is perfectly excludable such that only residents of state j gain the benefits of G_j.

[4] Porter (1978) found that there was no change in pre-tax price after the Oregon bottle bill was enacted. Dobbs (1991) also uses this assumption in his model. Eggert-W

[5] This assumption can be relaxed by letting $C^T$and K^T be increasing functions of x to reflect the household's choice of optimal trips.

properly disposing, and redeeming. Let x_i^L, x_i^D, and x_i^R denote the amount of good x in each disposal category, with $x_i = x_i^L + x_i^D + x_i^R$. If the household chooses to redeem good x, then they receive the redemption value τ_j. Since only state A has the bottle bill, this implies that $\tau_A = \tau > 0$ and $\tau_B = 0$. The marginal utility costs of disposal are given by c_i^L, c^D, and c_i^R where c_i^L and c_i^R are drawn from the distributions F^L and F^R, and c^D is constant across households. I make no assumptions on F^L and F^R but require that the marginal disposal costs be strictly positive. Let $C_i(x_i)$ be the disposal cost of good x for household i.

$$C_i(x_i) = c_i^L x_i^L + c^D x_i^D + c_i^R x_i^R \tag{3}$$

A household that disposes via redemption also incurs an indirect cost from traveling as given by (2). For a household in state A, the distance traveled to redeem is $\hat{d}_i = 0$. Since I assumed a continuum of stores, this implies that there is a continuum of RVM's as well. For households in state B, redemption implies that they must travel to the border and back so $\hat{d}_i = 2d_i$.

An important assumption is that the distributions F^T, F^L, and F^R are independent of each other and independent of distance. The location of a household in it of itself does not influence the likelihood of the household to have high or low cost draws. I assume that households do not choose d_i based on their cost draws.

The optimization problem for household i in state j is therefore given by:

$$\max V_{i,j} = U(x_i, y_i, G_j) - C_i(x_i) - C_i^T(\hat{d}_i) \tag{4}$$

$$\text{st. } M = [(1+t_j)p + \tau_j]x_i + (1+s_j)p_j y_i + K_i^T(\hat{d}_i) - \tau_A x_i^R - \bar{t}px_i\mathrm{I}_j \tag{5}$$

$$\text{st. } x_i = x_i^L + x_i^D + x_i^R \tag{6}$$

State governments wish to maximize social welfare. Each state has a fixed revenue requirement R. For state A which has a bottle bill, the government incurs an additional fixed cost $\hat{R}$. Government revenue comes from tax receipts on purchases of goods x and y. Since it is possible that not every household chooses to redeem, state A claims 75% of the escheat given by $\max\{(0.75)(\text{deposits-redemptions}), 0\}$. The surplus tax revenue is then applied towards producing the state public good G_j according to the production function $\Omega(z)$ where z is surplus revenue.

Disposal of good x creates an externality cost on society. Each unit littered, properly disposed, and redeemed creates externality cost e^L, e^D, and e^R. e^L can be interpreted as a marginal eyesore cost that affects everyone in the vicinity. It can also be seen as a marginal financial cost of cleaning up litter at a statewide level. e^D can be interpreted as the marginal cost of adding to the waste management/landfill burden. e^R can be interpreted as the marginal cost of collecting and processing an additional bottle (variable cost of the bottle bill). Following Dobbs paper, I assume that $e^L > e^D > e^R$. Given that all of good x must be disposed of in some fashion, a state would prefer the method which created the least cost.[6] If having a bottle bill had no fixed cost $\bar{R} = 0$, then every household redeeming would always be optimal. Conditional on already having a bottle bill, every household redeeming is again optimal.

Fraudulent redemption is dis-preferred by state A for three reasons. First, each container fraudulently redeemed removes τ in revenue which decreases the state public good G_A. Second, a state A household that fraudulently redeems must have cross-border shopped. This implies that inefficiency costs from traveling were incurred. Third, a state B household that redeems is also levies e^R in outside externality costs on Michigan. Under perfect enforcement, this household would have produced e^L or e^D in Ohio instead. State A also dis-prefers cross-border shopping by its residents. The household is incurring inefficiency costs from travel. Additionally, state A did not receive the tax receipts from that purchase.

3.1 Bottle Bill with Perfect Enforcement

Consider the case where state A can perfectly (and costlessly) enforce redemptions of only good x purchased in state A (ie. x for which the deposit was paid). Therefore, households in state A have the choice of littering, properly disposing, or redeeming. State B does not have the bottle bill so households can only choose to litter or properly dispose. Households in both states may cross-border shop for good x but the perfect enforcement condition will apply.

[6] Assume that the externality costs of disposal are not so high such that it would be more efficient to consume all good y. This is guaranteed by the assumptions on U.

3.1.1 State A

First, I look at the choice of littering versus properly disposing versus redeeming for a household that is not crossing. Since x^L, x^D, and x^R are prefect substitutes, the household will choose the disposal method that has the highest per-dollar marginal utility. Because $\hat{d}_i = 0$ for a redeeming household in state A, the household does not face any travel cost.

$$\frac{U_x - c_i^L}{(1+t_A)p+\tau} \; / \; \frac{U_x - c^D}{(1+t_A)p+\tau} \; / \; \frac{U_x - c_i^R}{(1+t_A)p} \tag{7}$$

A household that chooses between littering or properly disposing will look at the marginal costs. The probability of $c_i^L < c^D$ is given by $F^L(c^D)$. Thus, the first two terms of interest - the probabilities of a household littering/properly disposing conditional on not crossing and not redeeming - are given by:

$$\begin{cases} \mu & \equiv F^L(c^D) \\ 1-\mu & \equiv 1 - F^L(c^D) \end{cases} \tag{8}$$

Now consider the choice of redeeming. Denote $\bar{c}_i$ as the $\min\{c_i^L, c_i^D\}$. A household will choose to redeem if:

$$\triangle^R \equiv U_x - (1+t_A)p[\frac{U_x - \bar{c}_i}{(1+t_A)p+\tau_A}] \geq c_i^R \tag{9}$$

U_x is the marginal benefit of consuming an additional unit of x. The bracketed term is the per-dollar marginal utility of an additional unit of non-redeemed x, with $(1+t_A)p$ being the price of x^R. Since the household could have spent this money instead on non-redeemed x, the entire second term represents the marginal opportunity (utility) cost of x^R. Therefore, the entire left-hand side is the marginal benefit of x^R which is denoted as $\triangle^R$. The household will redeem if the benefit exceeds the cost. Note that $\triangle^R$ is not a function of distance since $\hat{d}_i = 0$.[7] This allows us to describe the probabilities of switching to redeeming conditional on littering/properly disposing.

$$\gamma_A^L \equiv \Pr(\triangle^R > c_i^R | (c_i^L < c^D)) \;=\; \frac{1}{\gamma} \int_0^{c^D} F^R(\triangle^R) f^L(c_i^L) \mathrm{d}c_i^L \tag{10}$$

$$\gamma_A^D \equiv \Pr(\triangle^R > c_i^R | (c_i^L > c^D)) \;=\; F^R(\triangle^R) \tag{11}$$

[7] Using this method gives us the same result as the total differentiation method in the next section.

This implies that of the μ fraction that would have littered without the option of redeeming γ^L fraction now choose to redeem. Likewise, γ^D fraction of the $1-\mu$ fraction of proper disposers choose to redeem.

$$\begin{cases} \mu(1-\gamma^L) & \Pr(\text{littering}) \\ (1-\mu)(1-\gamma^D) & \Pr(\text{properly disposing}) \\ \mu\gamma^L + (1-\mu)\gamma^D & \Pr(\text{redeeming}) \end{cases} \tag{12}$$

I now consider the choice of the household purchasing good x in the home state or crossing. For a given household in state j that is currently not redeeming, taking first-order conditions implies (13).

$$\frac{U_x - \bar{c}_i}{(1+t_A)p+\tau} = \frac{U_y}{(1+s_A)p_A} \tag{13}$$

From (5) and (13), a non-redeeming household's demand for good x and y is implicitly given by $x_i = \hat{x}_i(p, p_j, t_j, s_j, \tau_j, c_i, M)$ and $y_i = \frac{M}{(1+s_j)p_j} - \frac{(1+t_j)p+\tau}{(1+s_j)p_j}\hat{x}_i(p, p_j, t_j, s_j, \tau_j, c_i, M)$. The value function (4) can be re-written in terms of only $\hat{x}_i$.

$$V_{i,j} = U_i(\hat{x}_i, \frac{M}{(1+s_j)p_j} - \frac{(1+t_j)p+\tau}{(1+s_j)p_j}\hat{x}_i, G_j) - C_i(\hat{x}_i) \tag{14}$$

Totally differentiating the value function and plugging in for the FOC gives us:

$$\mathrm{d}V_{i,j} = U_y[-\tfrac{(1+t_j)\hat{x}_i}{(1+s_j)p_j}\mathrm{d}p - \tfrac{M-((1+t_j)p+\tau_j)\hat{x}_i}{(1+s_j)p_j^2}\mathrm{d}p_j - \tfrac{p\hat{x}_i}{(1+s_j)p_j}\mathrm{d}t_j$$

$$-\frac{M-((1+t_j)p+\tau_j)\hat{x}_i}{(1+s_j)^2 p_j}\mathrm{d}s_j - \frac{\hat{x}_i}{(1+s_j)p_j}\mathrm{d}\tau_j + \frac{1}{(1+s_j)p_j}\mathrm{d}M] - \hat{x}_i\mathrm{d}c \tag{15}$$

If a household in state A were to switch to crossing, this would imply a change in the tax $\mathrm{d}t = t_B - t_A = -\bar{t}$, a decrease in the deposit $\mathrm{d}\tau = -\tau$, a decrease in income $\mathrm{d}M = -K_i^T(\hat{d}_i)$, and an utility cost of travel given by $C_i^T(\hat{d}_i)$. Notice that the other key variables do not change: $\mathrm{d}p = 0$, $\mathrm{d}p_j = 0$, $\mathrm{d}s_j = 0$, and $\mathrm{d}c = 0$. Conditional on not redeeming, the household will switch if:

$$\nabla \equiv [\frac{U_x - \bar{c}_i}{(1+t_j)p+\tau}][(p\bar{t}+\tau)\hat{x}_i - K_i^T(\hat{d}_i)] \quad > \quad C_i^T(\hat{d}_i) \tag{16}$$

The first bracketed term on the left-hand side is the per dollar marginal utility of good x from (13). The second bracketed term is the net income gained (tax savings plus deposit savings less financial cost of travel). The entire left-hand side is therefore the utility benefit of switching which I denote as ∇. The term on the right-hand side is just the utility cost of travel. Let θ^L and θ^D represent the probabilities of a household crossing, conditional on not-redeeming as given by (17) and (18).

$$\theta^L \equiv \Pr(\frac{1}{\hat{d}_i}\nabla(c_i^L) > c_i^T|(c_i^L < c^D)) = \frac{1}{\gamma}\int_0^{c^D} F^T(\frac{1}{\hat{d}_i}\nabla(c_i^L))f^L(c_i^L)\mathrm{d}c_i^L \tag{17}$$

$$\theta^D \equiv \Pr(\frac{1}{\hat{d}_i}\nabla(c^D) > c_i^T|(c_i^L > c^D)) = F^T(\frac{1}{\hat{d}_i}\nabla(c^D)) \tag{18}$$

Now consider the choice of crossing for a household that is currently redeeming. A redeeming household faces a marginal disposal cost of c_i^R and an effective deposit of $\tau = 0$ since they are recouping the deposit by redeeming. Under perfect enforcement, a household in state A cannot do both. Switching to crossing results in a tax change $\mathrm{d}t = -\bar{t}$, financial cost of travel $\mathrm{d}M = -K_i^T(\hat{d}_i)$, and an utility cost of travel given by $C_i^T(\hat{d}_i)$ where $\hat{d}_i = 2d_i$. Additionally, the redeeming household must also switch to either littering or properly disposing$\mathrm{d}\bar{c} = \bar{c}_i - c_i^R$. All other parameters are unchanged. Conditional on redeeming, a household will cross if:

$$\nabla^R \equiv [\frac{U_x - c_i^R}{(1+t_j)p}][p\bar{t}\hat{x}_i - K_i^T(\hat{d}_i)] - \hat{x}_i(\bar{c}_i - c_i^R) > C_i^T(\hat{d}_i) \tag{19}$$

(19) is very similar to (16) except (19) does not have a τ term since the redeeming household was recouping the deposit amount. The other difference lies in the additional term that represents the switching of disposal method. Since I am conditioning on a household that is currently optimizing by redeeming, $\bar{c}_i$ will be greater than c_i^R implying that this is a cost. Denote the right-hand side as ∇^R. As before, let the probability of (19) being true be given by $\theta^{R,L}$ and $\theta^{R,D}$ which are characterized below.

$$\theta^{R,L} \equiv \Pr(\frac{1}{2d_i}\nabla^R(c_i^L) > c_i^T|(c_i^L < c^D)) = \frac{1}{\mu\gamma^L}\int\int_0^{c^D} F^T(\frac{1}{2d_i}\nabla^R(c_i^L))f^L(c_i^L)f^R(c_i^R)\mathrm{d}c_i^L\mathrm{d}c_i^R \tag{20}$$

$$\theta^{R,D} \equiv \Pr(\frac{1}{2d_i}\nabla^R(c^D) > c_i^T | (c_i^L > c^D)) = \int F^T(\frac{1}{2d_i}\nabla^R(c^D)) f^R(c_i^R) \mathrm{d}c_i^R \tag{21}$$

By switching to crossing, the household must revert back to either littering or properly disposing. This is determined by whether the household was part of the μ or the $1-\mu$ fraction which is reflected by the L and D superscripts in the θ terms.

Below, I summarize the key probability terms characterized in this section.

- μ : littering conditional on not cross-border shopping (crossing) and not redeeming
- $1-\mu$: properly disposing conditional on not crossing and not redeeming
- $\gamma^\bullet$: switching from littering/properly disposing to redeeming conditional on not crossing
- $\theta^\bullet$: switching to crossing conditional on previously littering/properly disposing
- $\theta^{R,\bullet}$: switching to crossing and littering/properly disposing conditional on previously redeeming

To express the behavior of households in state A in fraction, I integrate each probability over the range of d_i. Since only the θ terms are functions of distance, denote these integrals of θ by Θ.

$$\int_0^{\bar{d}_j} \theta(2d_i) h_j(d_i) \mathrm{d}d_i \equiv \Theta \tag{22}$$

Thus, the fraction of the population that chooses each action in state A is given below.

$$\begin{cases} \mu[(1-\gamma^L)\Theta^L + \gamma^L\Theta^{R,L}] & \text{cross/litter} \\ \mu[(1-\gamma^L)(1-\Theta^L) & \text{not cross/litter} \\ (1-\mu)[(1-\gamma^D)\Theta^D + \gamma^D\Theta^{R,D}] & \text{cross/properly dispose} \\ (1-\mu)(1-\gamma^D)(1-\Theta^D) & \text{not cross/properly dispose} \\ \mu\gamma^L(1-\Theta^{R,L}) + (1-\mu)\gamma^D(1-\Theta^{R,D}) & \text{not cross/redeem} \end{cases} \tag{23}$$

3.1.2 State B

Households in state B have the choice of redeeming but only if they also cross and purchase good x in state A. To characterize the behavior of state B households, I start with the standard characterization of μ from (8). For those households that are littering/properly disposing and not crossing, they have a choice of not switching, cross only, or cross and redeem.[8] Using the total differentiation method from (14) and (15), I can derive conditions under which the household will choose to switch or not switch.[9]

The non-redeeming and non-crossing household will switch to crossing if two conditions are met. First, the net utility gain of redeeming must be positive. This is associated with $\mathrm{d}t = \bar{t}$, $\mathrm{d}\tau = \tau$, $\mathrm{d}M = -K_i^T(\hat{d}_i)$, and an utility cost of $C_i^T(\hat{d}_i)$. Notice that redeeming for households in state B implies traveling $\hat{d}_i = 2d_i$. The second condition, which I denote as [A], requires that the net utility gain of $\mathrm{d}\tau = -\tau$ and $\mathrm{d}c = c_i^R - \bar{c}_i$ be negative. Following a similar procedure to (16) and (17), characterize and denote these probabilities as $\phi^{C,L}$, $\phi^{C,D}$, λ^L, and λ^D respectively. Notice that the ϕ and λ terms are independent of each other, and that only the ϕ terms are functions (decreasing) of distance.

Similarly, a household will switching to crossing and redeeming if two conditions are met. First, the net utility gain of crossing and redeeming must be positive. This is associated with $\mathrm{d}t = \bar{t}$, $\mathrm{d}M = -K_i^T(\hat{d}_i)$, $\mathrm{d}c = c_i^R - \bar{c}_i$, and an utility cost of $C_i^T(\hat{d}_i)$. The second condition is that the net utility gain of $\mathrm{d}\tau = -\tau$ and $\mathrm{d}c = c_i^R - \bar{c}_i$ be positive, ie. not [A]. I denote the probability of the first condition being true as $\phi^{CR,L}$ and $\phi^{CR,D}$. The probability of not [A] is given by $1 - \lambda^L$ and $1 - \lambda^D$. Again, the ϕ and λ terms are independent of each other, and only the ϕ terms are functions (decreasing) of distance.

I summarize the terms below.

- λ^L/λ^D : condition [A] is true conditional on previously littering/properly disposing and not crossing

- $\phi^{C,\bullet}\lambda^{\bullet}$: switching to crossing only conditional on previously littering/properly disposing and not crossing

[8] I previously assumed that the household makes at most one trip even though this household is choosing to cross and redeem at once. To get around this point, we can consider a household that is making the same choice across years/periods. Therefore, in the one trip for the current year/period, the household purchases good x for current consumption and redeems containers from the previous year/period.

[9] See appendix for proofs.

- $\phi^{CR,\bullet}(1-\lambda^{\bullet})$: switching to redeeming and crossing conditional on previously littering/properly disposing and not crossing

As in previous sections, I can integrate each of the terms ($\phi \rightarrow \Phi$) to describe the behavior of state B in fractions.

$$\begin{cases} \mu\Phi^{C,L}\lambda^{L} & \text{cross/litter} \\ \mu[1-\Phi^{C,L}\lambda^{L}-\Phi^{CR,L}(1-\lambda^{L})] & \text{not cross/litter} \\ (1-\mu)\Phi^{C,D}\lambda^{D} & \text{cross/properly dispose} \\ (1-\mu)[1-\Phi^{C,D}\lambda^{D}-\Phi^{CR,D}(1-\lambda^{D})] & \text{not cross/properly dispose} \\ \mu\Phi^{CR,L}(1-\lambda^{L})+(1-\mu)\Phi^{CR,D}(1-\lambda^{D}) & \text{cross/redeem} \end{cases} \tag{24}$$

3.1.3 Analysis

There are three cases to consider pertaining to the sign of $\bar{t}=t_A-t_B$. As a general comment, notice that the tax differential, $\bar{t}$, does not affect the baseline probabilities - μ, γ^L, and γ^D for state A. Conditional on not crossing, the choice of disposal method is independent of $\bar{t}$. As will be shown, $\bar{t}$ does however affect the end outcome. For state B, the choice of disposal method is always independent of $\bar{t}$ since redeeming with perfect enforcement. For state B, the relationship between $\bar{t}$ and $-\frac{\tau}{p}$ also makes a difference. Using the conditions from section 3.1.2, it can be shown that the relationship between $\bar{t}$ and $-\frac{\tau}{p}$ generates conditions on the sign of $\Phi^{C,\bullet}$ and $\Phi^{CR,\bullet}$ (proof omitted).

Case 1 - $\bar{t}>0 \rightarrow t_A>t_B$

When $\bar{t}>0$, the tax on good x in state A is greater than the tax in state B. This implies that for state A, $\Theta^{\bullet}$ and $\Theta^{R,\bullet}$ - fractions that cross when littering and when properly disposing, and fractions that cross when redeeming (else littering) and when redeeming (else properly disposing) - are strictly positive. The behavior of households in state A follows (23). For state B, $\bar{t}>0$ implies that there is no incentive to cross or cross and redeem. Therefore, the behavior of state B is given by (24) with $\Phi^{\bullet}$ and $\Phi^{CR,\bullet}$ equal to zero. Notice that the bottle bill has no effect on the behavior of households in state B in Case 1.

For state A, what are the properties of these four terms? Notice that all four terms are increasing in $\bar{t}$. As $\bar{t}$ increases this means that the tax savings and gains from crossing are increasing. All else being equal, the probability of a given household crossing and the total fraction of the population that choose cross should increase. Additionally, the four terms are increasing in the price of good x, p. A higher price implies a higher absolute tax savings. $\Theta^{\bullet}$ are also increasing in the deposit τ. For non-redeemers, crossing becomes more attractive for larger τ since the savings in purchase price is larger. τ does not however, affect $\Theta^{R,\bullet}$ since these redeemers were already recouping the deposit amount by redeeming. $\Theta^{R,\bullet}$ are also increasing in c_i^R. For higher marginal costs of redeeming, there is a smaller increase in disposal cost when the household crosses and switches back to littering or properly disposing. The probability of a given household to cross is decreasing in d_i, k_i^T, and c_i^T since each increases the costs of travel.

Since τ and $\bar{t}$ are two variables that the state governments can adjust, I will concentrate on the impact of these two. Notice that the model implies that the fraction of redeeming households decreases as distance to the border decreases. There should be relatively few households that actually redeem close to the border since most of them would find it less costly to cross and take advantage of the tax savings. This is an intuitive and unsurprising result. For those in state A that would have redeemed anyways, the magnitude of τ has no effect on households' likelihood to cross ($\Theta^{R,\bullet}$). This is a somewhat surprising result, but it does not mean that there is no change to the fractions of redeemers. Rather, the total fraction of redeemers, conditional on not crossing, increases but a constant proportion are then split into those that continue to redeem, and those that switch to cross. As such, the magnitude of τ increases the fraction of redeemers but also decreases the fraction of non-redeemers. Below, I look at the impact of a change in τ and $\bar{t}$.

- Change in τ

  An increase in τ causes an increase in $\gamma^{\bullet}$ and $\Theta^{\bullet}$. For state A, this unambiguously leads to a higher fraction of redeemers and a lower fraction of non-redeemers who do not cross-border shop, as previously mentioned. What is ambiguous however, is the effect on the fraction that cross. If $\Theta^{R,L}$ and $\Theta^{R,D}$ are relatively high ($\bar{t}$ large) then increasing τ creates more crossing, else it decreases. Regardless of $\bar{t}$, both the redemption rate $\left(\frac{\text{redemptions}}{\text{deposits}}\right)$ and fraction of redeemers in the population would increase. State B's behavior is unaffected but does see a change in the number of shoppers from state A depending on the size of $\bar{t}$.

- Change in $\bar{t}$

  For state A, an increase in $\bar{t}$ causes an increase in the fraction of cross-border shoppers. While $\bar{t}$ does not affect the baseline likelihood of households to choose a disposal method, it does cause redeemers to revert back to non-redeeming when they switch to crossing because of the greater incentives. Thus, we see that the fraction of litterers and proper disposers increases. The effect on the redemption rate is ambiguous. State B's behavior is unaffected but does see an increase in the number of shoppers from state A.

Case 2a - $\bar{t} < 0 \rightarrow t_A < t_B$ *and* $\bar{t} > -\frac{\tau}{p}$

When $\bar{t} < 0$, the tax on good x in state A is less than the tax in state B. For state A, $\Theta^{R,\bullet}$ are now both zero. Since none of these redeeming households were effectively paying the deposit, there is no incentive from crossing if the tax difference is unfavorable and the fraction of redeeming households is unaffected by the presence of state B. However, the sign of $\Theta^{\bullet}$ is uncertain. From crossing, these households pay more in taxes but they avoid paying the deposit. Thus, it is possible that Θ^{L} and Θ^{D} are positive if the tax difference is sufficiently small relative to the deposit ie. $|p\bar{t}| < \tau$. Under the assumptions of Case 2a, $\Theta^{\bullet}$ are both positive and increasing in both τ and $\bar{t}$.

For state B, $\bar{t} > -\frac{\tau}{p}$ implies that $\Phi^{C,\bullet}$ equals zero. However, the sign on $\Phi^{CR,\bullet}$ is ambiguous. $\Phi^{CR,\bullet}$ will be positive for large $\bar{t}$ (less negative), and zero for small $\bar{t}$ (more negative). This implies that the only households that cross are those that are also redeeming. $\Phi^{CR,\bullet}$ is increasing in $\bar{t}$ and unaffected by τ.

- Change in τ

  An increase in τ causes an increase in $\gamma^{\bullet}$ and $\Theta^{\bullet}$. For state A, this unambiguously leads to a higher fraction of redeemers and a lower fraction of non-redeemers. As in Case 1, the effect on the fraction that crosses is ambiguous. State B's behavior is unaffected since $\Phi^{CR,\bullet}$ is independent of τ. The fraction of redeeming crossers in state B remains constant. Regardless of $\bar{t}$, both the redemption rate and fraction of redeemers in the population of state A would increase.

- Change in $\bar{t}$

For state A, an increase in $\bar{t}$ has no effect on the fraction of redeemers. The choice of disposal method is unaffected. The only change that does occur is that the fraction of crossers increases. Households that were originally not crossing and not redeeming now switch to crossing. The increase in $\bar{t}$ causes the fraction of crossing redeemers to increase and the fraction of non-crossers to decrease. These two results imply that the redemption rate increases. However, this is being driven by the increase in out-of-state legitimate redemptions and the increase in crossers from state A. The fraction of state A redeemers stays constant.

Case 2b - $\bar{t} < 0 \rightarrow t_A < t_B$ *and* $\bar{t} < -\frac{\tau}{p}$

For state A, $\Theta^{R,\bullet}$ are again both zero. Additionally, $|p\bar{t}| \geq \tau$ also implies that $\Theta^{\bullet}$ are equal to zero. For state A, all households are non-crossers. For state B, $\Phi^{C,\bullet}$ and $\Phi^{CR,\bullet}$ are both positive and increasing in $\bar{t}$. Only $\Phi^{C,\bullet}$ is increasing in τ.

- Change in τ

  An increase in τ causes $\gamma^{\bullet}$ to increase. This in turn causes the fraction of redeemers to increase while decreasing the fraction of non-crossing litterers and proper disposers. For state B, the total fraction of crossers increase but the fraction of crossing redeemers stays the same. The fraction of non-crossing non-redeemers decreases and switch and become crossing non-redeemers. The change in the redemption rate is ambiguous but the redemption rate for state A households only has increased.

- Change in $\bar{t}$

  An increase in $\bar{t}$ has no effect on the behavior of state A since $\gamma^{\bullet}$ are independent of $\bar{t}$. For state B, an increase in $\bar{t}$ causes the fraction of crossing redeemers to increase. Overall, the total fraction of crossers increase. The fraction of non-crossing non-redeemers decreases. These households switch proportionally and become crossing redeemers and crossing non-redeemers. The change in the redemption rate is ambiguous since both redeeming and non-redeeming crossers from state B are increasing. The redemption rate for state A households is unchanged since the fraction is unchanged from an increase in $\bar{t}$.

Case 3 - $\bar{t} = 0 \rightarrow t_A = t_B$

For households in state A, $\Theta^{\bullet}$ are positive but $\Theta^{R,\bullet}$ are zero. $\Theta^{\bullet}$ is increasing in both τ and $\bar{t}$. For state B, $\bar{t} = 0 \rightarrow \bar{t} > -\frac{\tau}{p}$ and thus $\Phi^{C,\bullet}$ equals zero. $\Phi^{CR,\bullet}$ is positive. This implies that the only households that cross are those that are also redeeming. $\Phi^{CR,\bullet}$ is increasing in $\bar{t}$ and unaffected by τ.

- Change in τ

  For state A, an increase in τ leads to an increase in redeemers and a decrease in litterers and proper disposers. The effect on the fraction of crossers is ambiguous. Behavior in state B is unaffected. The redemption rate is weakly higher but the fraction of redeemers in state A has unambiguously increased.

3.2 Bottle Bill with No Enforcement

The fraudulent redemption of a relatively small number of bottles by a larger number of independent individuals is largely untouchable by state officers. First, there are not enough resources to cover every RVM location. Second, even if the resources were present, officers would not be able to determine which of the bottles were from out-of-state. An out-of-state redeemer may be legitimately redeeming if they had purchased the bottle within the state. Large-scale fraudulent redemption by organized groups are indeed detected and dealt with by law enforcement (eg. Operation Can Scam). Therefore, I ignore the case of imperfect enforcement and only consider the case where state A cannot enforce legitimate redemptions (perfect non-enforcement). Households in both states are able to redeem good x for which no deposit has been paid. Households in state A can now both cross and redeem. Households in state B now also have the choice of redeeming which incurs a travel cost equivalent to that incurred from crossing.

3.2.1 State A

This section closely follows the case of perfect enforcement. As from before, I first consider the disposal choice of a household that currently not crossing. This gave us the result shown below.

$$\begin{cases} \mu(1-\gamma^L) & \text{Pr(littering)} \\ (1-\mu)(1-\gamma^D) & \text{Pr(properly disposing)} \\ \mu\gamma^L + (1-\mu)\gamma^D & \text{Pr(redeeming)} \end{cases} \tag{25}$$

For a household that is currently purchasing good x in state A and not redeeming, when will they cross? (16) provided a condition for which household i would switch. (17) and (18) provided the characterization of θ^L and θ^D.

The first difference appears when considering the decision of a non-crossing redeemer. Under perfect enforcement, a household in state A cannot do both actions at once since good x is purchased in state B so $\mathrm{d}\tau = 0$. Under the case of no enforcement, the household can still redeem so $\mathrm{d}\tau = -\tau$. The second difference is that $\mathrm{d}\bar{c} = 0$. Since the household is able to redeem, it does not have to revert back to littering/properly disposing. Conditional on redeeming, a household will now cross if:

$$\nabla \equiv [\frac{U_x - c_i^R}{(1+t_A)p}][(p\bar{t} + \tau)\hat{x}_i - K_i^T(\hat{d}_i)] > C_i^T(\hat{d}_i) \tag{26}$$

Contrast (27) against (19) from the previous section. There is an increase to the utility gain from the additional $\tau\hat{x}_i$ term. Also, one of the cost terms, $-\hat{x}_i(\bar{c}_i - c_i^R)$, has disappeared since the household is still redeeming. Under no enforcement, it is obvious that redeeming households are more likely to cross than their counterparts under perfect enforcement. From (27), we can characterize $\theta^{R,L}$ and $\theta^{R,D}$ which we interpret as the probability of household i switching to crossing while still redeeming.

To describe the fraction of the population that chooses each different action, I again integrate the θ terms over the population density for all d_i.

$$
\begin{cases}
\mu(1-\gamma^L)\Theta^L & \text{cross/litter} \\
\mu(1-\gamma^L)(1-\Theta^L) & \text{not cross/litter} \\
(1-\mu)(1-\gamma^D)\Theta^D & \text{cross/properly dispose} \\
(1-\mu)(1-\gamma^D)(1-\Theta^D) & \text{not cross/properly dispose} \\
\mu\gamma^L\Theta^{R,L} + (1-\mu)\gamma^D\Theta^{R,D} & \text{cross/redeem} \\
\mu\gamma^L(1-\Theta^{R,L}) + (1-\mu)\gamma^D(1-\Theta^{R,D}) & \text{not cross/redeem}
\end{cases}
\tag{27}
$$

3.2.2 State B

Under no enforcement, households in state B now also have the choice of redeeming. To characterize the behavior of these households, I follow the same procedure from the perfect enforcement case. First, I consider the standard characterization of μ. For those households that are littering/properly disposing and not crossing, they have a choice of not switching or switching to cross only, redeem only, or cross and redeem. Using the total differentiation method, I derive conditions under which the household will choose to switch or not switch similar to before.[10]

A household will only consider switching to redeem when $\bar{t} > -\frac{\tau}{p}$. Conditionally, the household will switch if the net utility gain of redeeming is positive. Notice that redeeming for households in state B implies traveling $\hat{d}_i = \hat{d}_i$. The probability of the net utility being positive is given by $\phi^{R,\bullet}$.

Similarly, a household will only consider switching to cross only when $\bar{t} < -\frac{\tau}{p}$. If $\bar{t} < -\frac{\tau}{p}$ then the household will find this optimal if two conditions are met. The first condition requires that the net utility gain of cross only be positive. The second condition is [A] from the perfect enforcement case - the net utility gain of $\mathrm{d}\tau = -\tau$ and $\mathrm{d}c = c_i^R - \bar{c}_i$ must be negative. Following (24) and (25), the probability of the first condition being true is given by $\phi^{C,\bullet}$. Likewise, the probability of [A] was $\lambda^\bullet$.

Lastly, a household will only consider switching to cross and redeem when $\bar{t} < -\frac{\tau}{p}$. Again, there are two conditions for switching. The first condition requires that the net utility gain

[10] See appendix for proofs.

of crossing and redeeming be positive. The second condition is that [A] not hold. I denote the probability of the first condition being true as $\phi^{CR,\bullet}$. The probability of not [A] is given by $1-\lambda^{\bullet}$.

Again, all of the ϕ terms are decreasing functions of distance since both crossing and redeeming require travel. The key probability terms for households in state B are denoted differently from households in state A. I summarize the terms below.

- λ : condition [A] is true
- $\phi^{R,\bullet}$: switching to redeeming only conditional on previously littering/properly disposing and not crossing
- $\phi^{C,\bullet}\lambda^{\bullet}$: switching to crossing only conditional on previously littering/properly disposing and not crossing
- $\phi^{CR,\bullet}(1-\lambda^{\bullet})$: switching to redeeming and crossing conditional on previously littering/properly disposing and not crossing

As in previous sections, I can integrate each of the terms to describe the behavior of state B in fractions. (29) and (30) pertain to the cases of $\bar{t} > -\frac{\tau}{p}$ and $\bar{t} < -\frac{\tau}{p}$ respectively.

$$\begin{cases} \mu(1-\Phi^{R,L}) & \text{litter} \\ (1-\mu)(1-\Phi^{R,D}) & \text{properly dispose} \\ \mu\Phi^{R,L} + (1-\mu)\Phi^{R,D} & \text{redeem} \end{cases} \tag{28}$$

$$\begin{cases} \mu\Phi^{C,L}\lambda & \text{cross/litter} \\ \mu[1-\Phi^{C,L}\lambda - \Phi^{CR,L}(1-\lambda)] & \text{not cross/litter} \\ (1-\mu)\Phi^{C,D}(1-\lambda) & \text{cross/properly dispose} \\ (1-\mu)[1-\Phi^{C,D}-\Phi^{CR,D}(1-\lambda)] & \text{not cross/properly dispose} \\ \mu\Phi^{CR,L}(1-\lambda) + (1-\mu)\Phi^{CR,D}\lambda & \text{cross/redeem} \end{cases} \tag{29}$$

3.2.3 Analysis

Again, I consider the three possible cases pertaining to the sign of $\bar{t}$.

Case 1 - $\bar{t} > 0 \rightarrow t_A > t_B$

For state A, the four terms are both positive. Their properties identical to the previous case, except for one difference. $\Theta^{R,\bullet}$ are now also increasing in τ. Under the previous case of perfect enforcement, τ had no effect on the fraction of redeeming households that switched to crossing. For state B, the behavior of households follows (28) since $\bar{t} > 0 \rightarrow \bar{t} > -\frac{\tau}{p}$. Thus, $\Phi^{R,\bullet}$ - the fractions that redeem - are both positive and, increasing in τ and $\bar{c}_i$.

- Change in τ

  For state A, an increase in τ causes redeeming to increase as well as crossing. More specifically, the fraction that cross and redeem together increases (in-state fraudulent redemption). For state B, the increase leads to more redeeming (out-of-state fraudulent redemptions). Combining the two results, we see that an increase to τ would increase the redemption rate. However, this is this being driven more by fraudulent redemptions rather than legitimate ones. The fraction that legitimately redeem is bell shaped such that the first derivative is initially positive, then zero, and then negative for increasing τ.

- Change in $\bar{t}$

  For state A, an increase in $\bar{t}$ causes an increase in the fraction of crossers but no change in the breakdown of disposal methods. Under perfect enforcement, an increase in $\bar{t}$ led to less redeeming since households were forced to stop redeeming after crossing. Under no enforcement, this effect goes away since redeeming households will still redeem after crossing. State B's behavior is unaffected. Therefore, we see that an increase in $\bar{t}$ leads to an increase in the redemption rate. However, this is driven entirely by the shift to fraudulent redemptions since deposits are decreasing while redemptions are staying the same.

Case 2a - $\bar{t} < 0 \rightarrow t_A < t_B$ and $\bar{t} > -\frac{\tau}{p}$

For state A, the four terms are again positive and have the same properties. Likewise, behavior of state B is still given by (29) with $\Phi^{R,\bullet}$ both positive and, increasing in τ and $\bar{c}_i$. However, the total fraction of crossers in state A is lower. Notice that state B still has no crossers even though there are redeemers.

- Change in τ

  In response to an increase in τ, state A and state B react the same as in Case 1.

- Change in $\bar{t}$

  The response is the same as in Case 1.

Case 2b - $\bar{t} < 0 \rightarrow t_A < t_B$ *and* $\bar{t} < -\frac{\tau}{p}$

For state A, the four terms are all equal to zero since the conditions imply that increase tax outweighs the savings in the deposit. There is therefore no incentive for any household in state A to cross. The behavior of state B is now given by (30). $\Phi^{C,\bullet}$ and $\Phi^{CR,\bullet}$ are positive while $\Phi^{R,\bullet}$ are both zero. Households in state B choose to cross or cross and redeem, and no longer only redeem. The $\Phi^{C,\bullet}$ terms are increasing in $\bar{t}$ and decreasing in τ. The $\Phi^{CR,\bullet}$ terms are increasing in $\bar{t}$ and $\bar{c}_i$ but unaffected by τ.

- Change in τ

  For state A, an increase in τ causes redeeming to increase. Since there is no crossing, there is an unambiguous increase in legitimate in-state redemptions. For state B, an increase in τ causes the fraction of crossers to decrease. Specifically, the fraction that cross and are not redeeming decreases while the fraction that cross and redeem stays the same. Additionally, there is no change in the breakdown of disposal methods. Combining these two results, we see that an increase in τ causes an increase to the redemption rate driven entirely by legitimate redemptions since there is no effect on out-of-state redeemers.

- Change in $\bar{t}$

  For state A, an increase in $\bar{t}$ does not affect the behavior of state A. For state B, it increases the total fraction that cross. It also increases the fraction that are crossing and redeeming. Specifically, the fraction of households who were previously not crossing and not-redeeming are being pulled into cross and not-redeeming, and crossing and redeeming. The change to the redemption rate is ambiguous as it depends on the relative change in the cross and not redeeming fraction versus the cross and redeem fraction.

Case 3 - $\bar{t} = 0 \rightarrow t_A = t_B$

$\bar{t} = 0$ implies that $\bar{t} > -\frac{\tau}{p}$, which makes Case 3 similar to Case 1. The four terms are again positive and have the same properties (increasing in τ), although they are lesser in magnitude. Notice that with Case 3 and perfect enforcement, τ had no effect on those already redeeming but not crossing. As in Case 1, τ now affects redeeming and crossing as well. For households in state B, $\Theta^{\bullet}$ are also equal to zero. For state B, the behavior of households again follows (29) with $\Phi^{R,\bullet}$ both being positive and, increasing in τ.

- Change in τ

  In response to an increase in τ, state A and state B react the same as in Case 1.

4 Case Study - Michigan

I now consider the specific case of Michigan. Michigan is bordered by the three non-bottle bill states of Ohio (to the southeast), Indiana (to the southwest), and Wisconsin (to the northwest). Michigan therefore has about 150 miles of shared borders. Also, Michigan is a rarity in that it has a ten cent deposit as opposed to the more common five cent deposit. This generates a great deal of incentives for out-of-state households to fraudulently redeem in Michigan. Likewise, residents in Michigan have an incentive to purchase eligible containers in other states such as Ohio, and fraudulently redeem them in Michigan. A case of 24 beers purchased in Ohio and then redeemed in Michigan will reduce the purchase price by $2.40 (ten cents for every container) in addition to the differences in excise and sales taxes (see Table 1).

Stultz-Gilbert (2000) estimated that between 50 and 150 million containers were fraudulently redeemed in 1995 using raw redemption-deposit data and extrapolations from the stream of recycled materials within Michigan. This would imply that between $5 and $15 million in escheat was lost. Likewise, residents in Michigan have an incentive to purchase eligible containers in Ohio, and fraudulently redeem in Michigan. The 2001-2002 Annual Report of the State Treasurer showed that deposit receipts versus disbursements (redemptions) were \$36.22 million and \$34.96 million. The following year, this turned into \$31.71 million and \$34.77 million. Since then gap widened and peaked at around \$10 million in excess of receipts in the 2004-2005 calendar year. Receipts were \$26.7 million while disbursements were \$36.74 million. The model implies that the \$10 million gap (1 million bottles) that were redeemed in excess of the 100% return rate is a crude lower bound on the true amount of fraudulent redemptions. If I use data from the 1998-1999 and 2000-2001 years as a naive approximation of the legitimate redemption rate (~90% for both years), then during the 2004-2005 year, the true fraudulent redemption amount was \$12.71 million.

The most recent 2007-2008 data showed that the gap had actually dropped below zero such that receipts were \$23.04 million while disbursements were \$22.97 million. This recent drop is attributed to the strong reaction by the state to step up enforcement. After seeing unequivocal evidence of massive fraudulent redemptions, the state passed an updated bottle bill specifically addressing the issue of fraudulent redemption. The RVM Anti-fraud Act (a combination of six house bills HLA's) was passed in late 2009. It called for the creation of a fund to support the installation of new RVM's that could detect out-of-state bottles. These new RVM's, along with requirements on bottlers to redesign bottles to allow for detection, are slated to be installed in late July of 2010. The Act required that such RVM's be mandatory in the border counties where fraudulent redemption was most likely.[11]

4.1 Predicted Responses

The model can make some predictions on the effect of this new law. For this section, I concentrate on the dynamic between Michigan and Ohio. For Ohio households (state B), implementing these new RVM's increases $\hat{d}_i$ - travel distance - by a fixed, positive amount $\triangle\hat{d}$ for every Ohioan since the nearest usable RVM is now located in a more northern Michigan county. Since the tax rate is higher in Michigan than in Ohio, we are in Case 1 of the model.

[11]The list of counties is officially broken down into "true border counties" which have a border, and then the secondary border counties which are a line of southern counties contiguous to the true border counties. This includes Wayne and Washtenaw county were Detroit and Ann Arbor are located.

The behavior of households in Michigan is given by (27), and the behavior of households in Ohio is given by (28). I first look at the impact of this change on Ohio households.

Ohio households have no incentive to cross-border shop in Michigan. The population of Ohio is broken down into litterers, proper disposers, and redeemers (fraudulent). For an increase in $\hat{d}_i$, the fraction and total number of households that redeem should decrease. This decrease in redeeming households is approximately:

$$Q^o N_{ohio} \equiv |\frac{\partial}{\partial \hat{d}_i}[\mu \Phi^{R,L} + (1-\mu)\Phi^{R,D}](\triangle \hat{d})(N_{ohio})| \tag{30}$$

To simplify the analysis, I again assume that each household purchases one unit of good x so that $Q^o N_{ohio}$ is now also the decrease in out-of-state fraudulent redemptions. We can analogously define the increase in littering and proper disposing as a result of the policy by $\beta^L N_{ohio}$ and $\beta^D N_{ohio}$. What does this imply for Ohio? The amount of litter in Ohio will increase by $\beta^L N_{ohio}$ which implies that the increase in externality cost will be given by $\beta^L N_{ohio} e^L$. Likewise, the increase in proper disposers creates $\beta^D N_{ohio} e^D$ in additional externality costs. The fact that $Q^o N_{ohio}$ households are no longer redeeming in Michigan also implies that externality costs in Michigan decrease by $Q^o N_{ohio} e^R$. However, the decrease in redeeming also decreases the inefficiency costs incurred via travel for Ohio.

Ohio households are not the only source of fraudulent redemption. Michigan households also contributing in-state fraud since they cross-border shop and redeem. How does this policy affect these Michigan households? Notice that for those households that are crossing and redeeming but live in a non-border county, they are not affected. The only households in Michigan that are affected are the crossing and redeeming households that live within the border counties. These households cannot redeem without traveling some additional distance. This implies that $\hat{d}_i > 2d_i$ for these crossing redeemers. The increased travel cost now increases the probability that these households switch and become non-crossing redeemers. Notice that the increase to $\hat{d}_i$ is largest for those households living closest to the border - d_i close to zero. This implies that those households originally with the most incentive to cross and fraudulently redeem, now also have the most incentive to stop crossing and legitimately redeem.

$$\nabla \equiv [\frac{U_x - c_i^R}{(1+t_A)p}][(p\bar{t} + \tau)\hat{x}_i - K_i^T(2d_i)] > C_i^T(\triangle \hat{d}) \tag{31}$$

Next, I integrate the probability of the above equation over $d_i \in [0, \triangle\hat{d}]$. Subtracting the fraction of households who still cross and redeem from the original fraction gives us the fraction that switch to legitimate redemption. Define this fraction as Q^m which implies that the number of switching households is given by $Q^m N_{michigan}$. The policy increases Michigan's revenue by $Q^m N_{michigan}\tau$. These switching households also no longer incur the inefficiency costs of travel since they can legitimately redeem with $\hat{d}_i = 0$. However, the fraction of households that still chooses to cross and redeem lose additional travel costs since $\hat{d}_i$ increases by $\triangle\hat{d}$.

Overall, the policy causes the number of fraudulent redeemers to decrease by $Q^o N_{ohio} + Q^m N_{michigan}$ and the amount of fraudulent redemptions to decrease by $\tau[Q^o N_{ohio} + Q^m N_{michigan}]$. Externality costs have also decreased since $Q^o N_{ohio}$ Ohio households are no longer redeeming in Michigan. The impact on inefficient travel costs is ambiguous since some households are traveling less while others are traveling more. Additionally, Michigan needs to consider the cost of implementing this policy. The Anti-fraud Act was supposed to have set aside a $500,000 fund to cover costs although this does not include other non-direct costs. As far as decreasing fraudulent redemptions however, this policy should succeed.

5 Conclusion

Early works looking at the impact of bottle bills failed to take into account the effects of having a bordering state that did not share the same bottle policy. Without perfect enforcement, there are incentives for households in both states to take on socially inefficient actions. This model characterized the behavior of households in both the bottle bill state and non-bottle bill state under various cases. The implementation of a bottle bill, or an increase in the deposit, may not always generate a gain in social welfare under no enforcement even if such were the case under perfect enforcement. This is something that has largely been ignored in the literature. Also, the model was able to make predictions on the impact of the Anti-fraud Act in Michigan.

The model is a useful framework for analyzing other aspects of the bottle bill and other potential policy changes. An alternative approach to curbing fraudulent redemptions is to decrease the bottle deposit. As was shown in the analyses sections, a high redemption rate is not necessarily indicative of a high in-state redemption rate. This would decrease for fraudulent redemptions but it would also decrease incentives for redemptions on the whole. In terms of policy prescriptions that could completely disincentivize fraudulent redemptions, one method is to align the bottle policies between neighboring states. If Ohio also had a bottle bill with an equivalent ten cent deposit, then this would get rid of incentives for fraudulent redemption between the two states. One issue with this notion is that Ohio might find it in its interest to not implement a bottle bill but rather, free-ride off of Michigan. As previously mentioned, Ohio could be benefiting as a whole since it decreases social disposal costs and increases tax revenue. In this case, Ohio would never voluntarily choose to implement a bottle bill if Michigan already has one. Second, Michigan and Ohio both have other neighbor states. For Michigan, fraudulent redemption also occurs in the north with Wisconsin and also to the southwest with Indiana. Even if Ohio were to implement an identical bottle bill, Michigan would still see fraudulent redemption coming from Wisconsin and Indiana. Likewise, Ohio would now face its own fraudulent redemption problem from Kentucky and West Virginia.

There are two solutions to addressing fraudulent redemptions. First, there is an optimum distance for which to install these new RVM's such that the decrease in marginal efficiency and revenue costs is equal to the marginal cost of installing another RVM. Ideally, if the technology to produce sophisticated RVM's become cheap enough, then all RVM's would be fitted to prevent fraudulent redemption. Second, if all states adopted the same bottle policy or were compelled to do so by the federal government, then fraudulent redemption would also be stopped. Short of these two methods, fraudulent redemptions are likely to remain a part of the Michigan bottle bill situation, and serve as a deterrent for non-bottle bill states to enact similar policies.

6 Tables

Table 1 - Taxes in Michigan and Ohio (2009)

	Sales	Beer (\$/gal)	Spirits (\$/gal)	Table Wine (\$/gal)
Michigan	6%	\$0.20	\$10.91	\$0.51
Ohio	5.5%	\$0.18	\$9.04	\$0.32

Source: http://www.taxfoundation.org/taxdata/show/245.html

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