

CONSUMER RESPONSE TO CIGARETTE EXCISE TAX CHANGES

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MODEL APPENDIX

A. Model Derivation

In this section, we derive the first order conditions for the analytic solution to the Bellman model presented in (1), where the consumer does not face adjustment costs. Although we do not solve for a closed form solution of the more general model with adjustment costs, the intuition from the model without adjustment costs applies to the more general case.

Absent adjustment costs, consumers choose purchases x_t^H, x_t^L and consumption c_t^H, c_t^L of two quality tiers H, L of a particular good to maximize the value function

$$\begin{aligned} \text{[A-1]} \quad V(A_0) &= \max_{\{c_t^H, c_t^L, x_t^H, x_t^L\}} \sum_{t=0}^{\infty} \left(\frac{1}{1+\delta}\right)^t (u[c_t^H + \eta c_t^L]) \\ \text{s.t.} \quad A_{t+1} &= (1+r)(y_t + A_t - p_t^H x_t^H - p_t^L x_t^L) \\ I_{t+1}^H &= (I_t^H - c_t^H + x_t^H) \\ I_{t+1}^L &= (I_t^L - c_t^L + x_t^L) \end{aligned}$$

with non-negativity constraints for consumption, purchases, and inventories of the good $c_t^H, c_t^L, x_t^H, x_t^L$, and I_t^H, I_t^L . A_t denotes a consumer's wealth or assets at the start of period t . The parameters δ and r denote a consumer's discount rate and the real interest rate on assets.

We first consider the model in which consumers cannot stockpile the good. That is, analytically solve the constrained model where $c_t^H = x_t^H, c_t^L = x_t^L$ and $I_t = 0$ for all t . To derive the optimal path of consumption in this case, we rewrite the objective function recursively as a Bellman equation.

$$\text{(A-2)} \quad V(A_t) = \max_{\{c_t^H, c_t^L\}} (u[c_t^H + \eta c_t^L]) + \frac{1}{1+\delta} V(A_{t+1})$$

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$$\begin{aligned} \text{s.t.} \quad A_{t+1} &= (1+r)(y_t + A_t - p_t^H c_t^H - p_t^L c_t^L) \\ c_t^H, c_t^L &\geq 0 \end{aligned}$$

We then take first-order conditions for (A-2) with respect to c_t^H and c_t^L .

$$\frac{\partial u}{\partial c_t^H} + \frac{1}{1+\delta} \frac{\partial V(A_{t+1})}{\partial A_{t+1}} \frac{\partial A_{t+1}}{\partial c_t^H} + \mu_t^H = 0$$

$$\frac{\partial u}{\partial c_t^L} + \frac{1}{1+\delta} \frac{\partial V(A_{t+1})}{\partial A_{t+1}} \frac{\partial A_{t+1}}{\partial c_t^L} + \mu_t^L = 0$$

By the envelope theorem, the marginal utility of increasing A_{t+1} is equal to the marginal utility of consumption at time $t+1$. Consequently, we can rewrite the previous two FOCs as Euler equations equating intertemporal marginal utility from buying high and low-quality cigarettes. In addition, equating the two FOCs (using the partial derivative of $V(A_{t+1})$ with respect to A_{t+1}), we derive a third equation that equates the contemporaneous marginal utilities of different quality tiers:

$$\frac{\partial u}{\partial c_t^H} - \mu_t^H = \frac{1+r}{1+d} \frac{p_t^H}{p_{t+1}^H} \frac{\partial u}{\partial c_{t+1}^H} - \mu_{t+1}^H$$

$$\frac{\partial u}{\partial c_t^L} - \mu_t^L = \frac{1+r}{1+d} \frac{p_t^L}{p_{t+1}^L} \frac{\partial u}{\partial c_{t+1}^L} - \mu_{t+1}^L$$

$$\eta - \mu_t^H = \frac{p_t^L}{p_t^H} - \mu_t^L$$

The first two sets of first-order conditions (FOCs) equate the marginal discounted utility of consumption of the high- and low-quality goods between periods. For a consumer who strictly prefers the high- (or alternatively, low-) quality tier in all periods, the first (second) equation

defines the optimal path of consumption. Consumption falls with prices and follows a declining (rising) trend if the discount rate is greater (less) than the interest rate on savings.

The third equation defines the subset of consumers who will purchase the low-quality tier in a particular period. If a consumer's relative preference for the low-quality good, η , is greater than the relative marginal cost, p_t^L/p_t^H , the consumer purchases the low-quality good in a given period and the Kuhn-tucker condition for H binds ($\mu_t^H > 0, \mu_t^L = 0$). Similarly, if $\eta < p_t^L/p_t^H$, the consumer chooses to purchase the high-quality good. If per-unit taxes increase the level of both the high-quality and low-quality good ($p_{t+1}^H = p_t^H + \tau$, and $p_{t+1}^L = p_t^L + \tau$), consumers with η in $(p_t^L/p_t^H, p_{t+1}^L/p_{t+1}^H)$ will strictly prefer the low-quality good before the tax change and strictly prefer the high-quality good after the tax change. The substitution from low- to high-quality goods, along with the per-unit tax increase causing a bigger relative price increase for low-quality goods drives the familiar "flight-to-quality" result documented in the previous literature.

B. Sensitivity Analyses

In this section, we examine the sensitivity of the low-quality tier quantity to changes in our simulation parameters. To restate, our base specification assumes the following:

- The starting price of the high-quality and low-quality tiers are 10 and 8 respectively.
- A per-unit tax of 2 is imposed at time $t = 10$.
- Consumers discount future utility at 10 percent. Assets (or liability) appreciate at 10 percent.
- A consumer's relative preference for low-quality cigarettes (η is uniformly distributed from [0.7, 0.9]. Absent adjustment costs, consumers with $\eta < 0.8$ always prefer high-quality cigarettes. Consumers with η in [0.8, 0.833] switch from low to high-quality

cigarettes following the tax change. Consumer with $\eta > 0.833\$$ always purchase low-quality cigarettes.

In this appendix, we focus on two parameters: (i) the magnitude of the tax increase, and (ii) the consumer discount rate. Changing the starting prices and the distribution of η will change the proportion of consumers in each of the three groups, but do not the quantity conclusions.

Figure A-1 graphs the quantity of the lowest quality tier for per-unit tax increases of \$1 - \$4 (\$2 is the reference case). As the per-unit tax increases, stockpiling increases, particularly for the low-quality good for which the tax increase is of greater magnitude. Second, in the long-term, a larger per-unit tax increase encourages a larger flight to the high quality good, by increasing the proportion of consumers who switch from the low-quality to the high-quality good in response to the tax change.

Figure A-1. Sensitivity Analysis: Per-unit Tax Increase

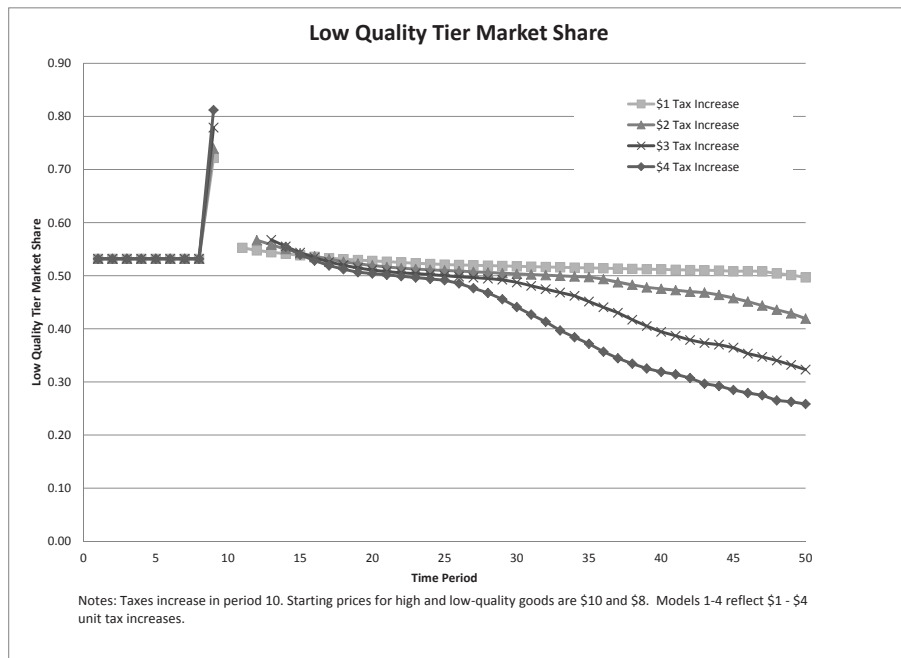
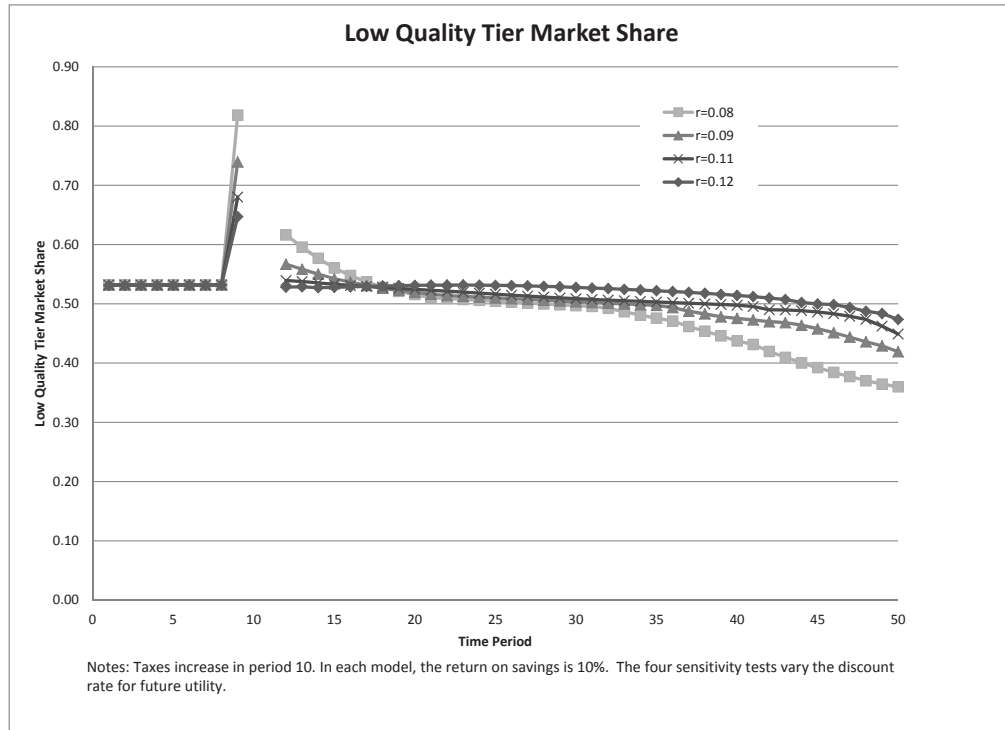


Figure A-2 graphs the quantity of the lowest quality tier for four discount rates (the reference case $d = 0.1$ is omitted). As before, the discount rate is correlated with stockpiling as well as the long-term trend, but the short-term flight from quality is robust to the changes.

Figure A-2: Sensitivity Analysis: Discount Rate

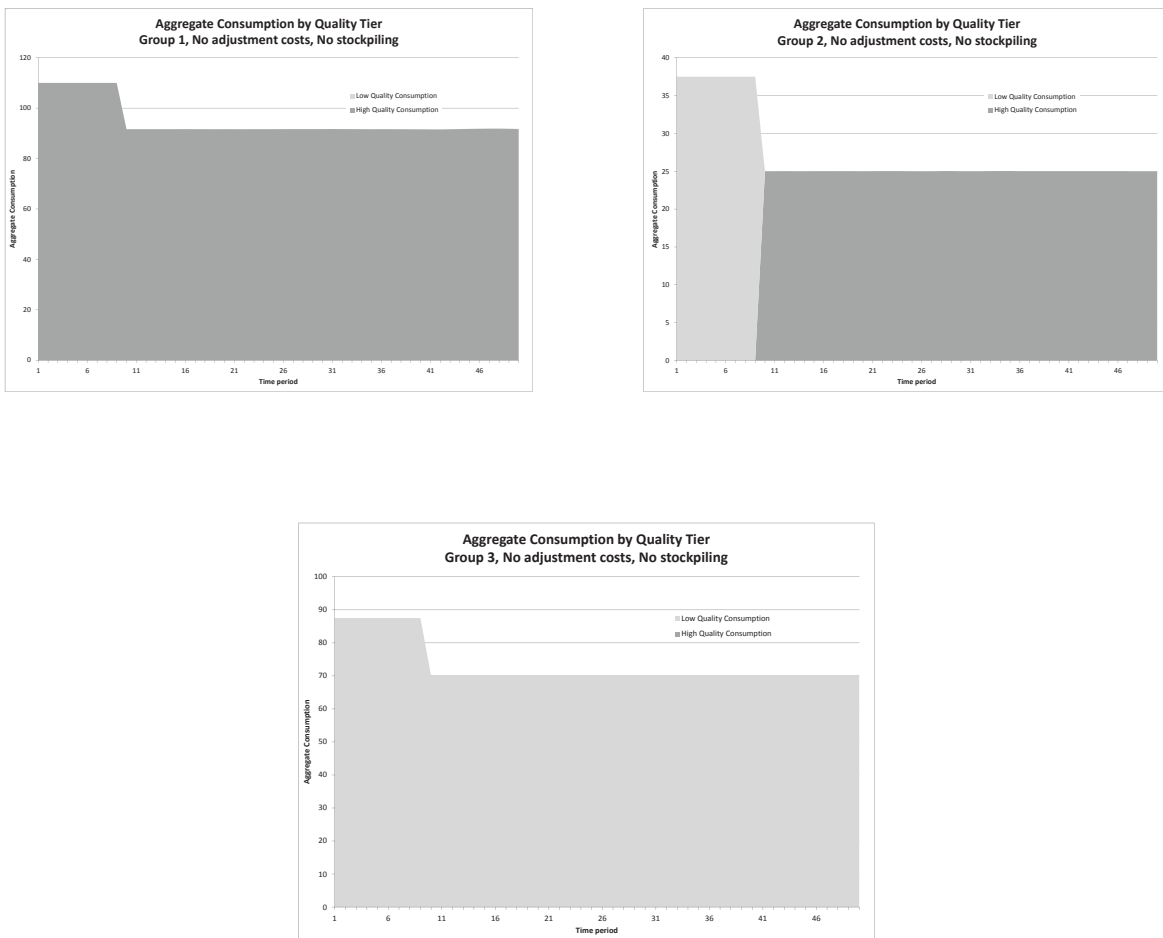


C. Quantity Decomposition

In this section, we decompose the quantity of the low-quality tier into consumption of the high and low-quality tiers. In particular, we separately examine consumption for each of three consumer “classes”: (1) consumers who always consume H absent adjustment costs ($\eta < 0.8$), (2) consumers who switch from L to H absent adjustment costs (η in $[0.8, 0.833)$), and (3) consumers who always consume L absent adjustment costs ($\eta \geq 0.833$).

We first present the quantity decomposition for the reference case, the model without adjustment costs and stockpiling. In this case, in the aggregate, we see an immediate flight to quality, driven by the behavior of the consumers who switch from consuming the low quality good to the high quality good.

Figure A-3: Cigarette Consumption by Tier and Consumer Group: Baseline Case



Second, we present the quantity decomposition for model 2 in figure 2. Unlike the previous example, consumers face quadratic adjustment costs when reducing consumption, where the adjustment costs are measured relative to consumption in the previous period. With

adjustment costs, we no longer see a sharp discontinuity in consumption at the time of the tax increase. Rather, we see all three groups gradually taper their consumption to lower levels. Group 1, the consumers who always consume high-quality cigarettes absent adjustment costs, now smooth their transition path by consuming low-quality cigarettes for five periods after the tax change. Group 2, the consumers who switch immediately from low-quality to high-quality cigarettes absent adjustment costs, now delay the switch substantially to mitigate adjustment costs. Group 3, which cannot substitute to lower quality cigarettes, responds by borrowing against future periods to smooth the transition path after the tax change.

Finally, we present the quantity decomposition for model 2 in figure 3. In this case, consumers can partially mitigate adjustment costs by stockpiling goods prior to the tax change at $t=10$. Although stockpiling does not change the general shape of the transition path, it does allow consumers to maintain a higher level of cigarette consumption in the post-tax period.

Figure A-4: Cigarette Consumption by Tier and Consumer Group: Adjustment Costs, No Stockpiling

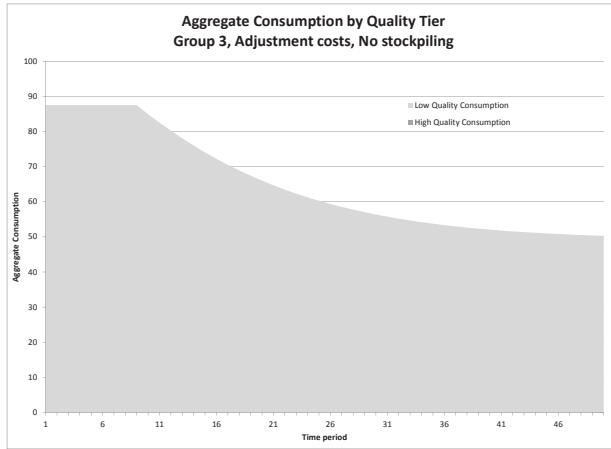
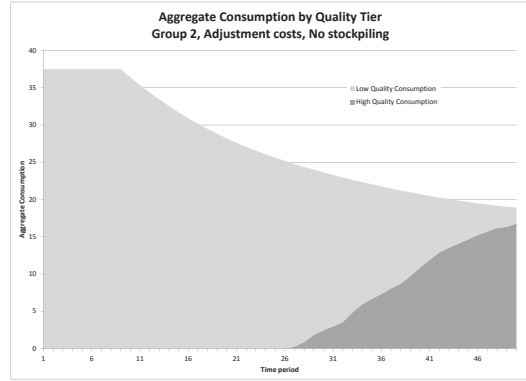
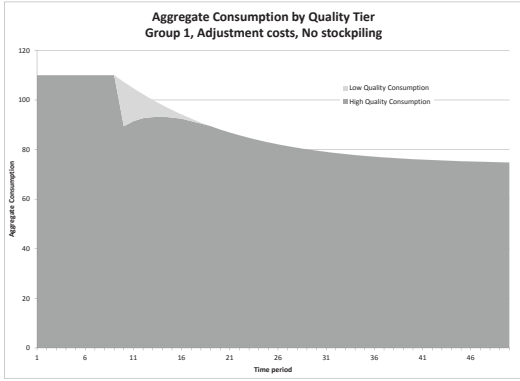


Figure A-5: Cigarette Consumption by Tier and Consumer Group: Adjustment Costs, No Stockpiling

