Online Appendix: Theory

Proofs of Claims, Propositions and Theorems

Proof of Proposition 1

Proof. Discrete Choice: This is a consequence of the Williams-Daly-Zachary Theorem (see McFadden 1981) which states that $\frac{\partial CS(p_1,\ldots,p_J,J)}{\partial p_j} = -q_j(p_1,\ldots,p_J,J)$. Therefore, $\frac{dCS(p,J)}{dp} = \sum_{j=1}^{J} \frac{\partial CS(p,\ldots,p,J)}{\partial p_j} = -Q(p,J)$. If follows that

$$CS(p,J) = \int_p^\infty Q(s,J)ds + \frac{1}{\alpha}\mathbb{E}[u_{i0}].$$

Continuous Choice (full statement and proof):

If the consumer has preferences given by $u(q_1,\ldots,q_J,m) = h_J(q_1,\ldots,q_J) + m$ for any h_J symmetric in all its arguments, continuously differentiable, strictly quasi-concave and $h(\mathbf{0}) = 0$, and if the consumer faces symmetric prices $p_j = p$, we can represent consumer surplus as

$$CS(p,J) \equiv u^*(p,J,y) = \int_p^\infty Q(s,J)ds + y. \tag{22}$$

It can be seen by writing the indirect utility function as

$$u^*(p,J,y) = H_J(Q(p,J)) + y - p * Q(p,J) = \int_0^{Q(p,J)} P(s,J) + y - p * Q(p,J) = \int_p^\infty Q(s,J)ds + y$$

□

Proof of Theorem 1

Proof. Average change in willingness to pay for inframarginal units is:

$$\overline{\frac{\partial P}{\partial J}}(Q,J) = \frac{1}{Q}\int_0^Q \frac{\partial P}{\partial J}(s,J)ds.$$

Integrating by parts we get:

$$\Lambda = \int_p^\infty \frac{\partial Q}{\partial J}(s,J)ds = \int_0^Q \frac{\partial P}{\partial J}(s,J)ds = Q\overline{\frac{\partial P}{\partial J}}.$$

Now, assume for some J, J' inverse aggregate demands are parallel, $\frac{\partial P}{\partial Q}(Q,J) = \frac{\partial P}{\partial Q}(Q,J')$, then there exists d such that $P(Q,J) = P(Q,J') + d$, the variety effect is given by

$$\Lambda(J,J') = \int_0^{Q(p,J)} P(s,J)ds - \int_0^{Q(p,J')} P(s,J')ds = Q(p,J) * d - \int_{Q(p,J)}^{Q(p,J')} P(s,J')ds.$$

Taking the limit as $J' \to J$ then $d \to \frac{\partial P}{\partial J}(Q,J)$, furthermore $\frac{\partial P}{\partial J}(Q,J)$ is constant so

$$\overline{\frac{\partial P}{\partial J}}(Q,J) = \frac{\partial P}{\partial J}(Q,J) = \frac{dP(Q(J),J)}{dJ} - \frac{\partial P}{\partial Q}(Q,J)\frac{dQ(J)}{dJ} = \left(\frac{dP}{dQ} - \left.\frac{dP}{dQ}\right|_J\right)\frac{dQ}{dJ}$$

where $\frac{dP}{dQ} = \frac{dP(Q(J),J)}{dJ} / \frac{dQ}{dJ}$. □

Gumbel is the unique iid distribution satisfying inverse parallel demands

We have shown a sufficient condition to get inverse parallel demands is that the random utility shocks (ε_{ij}) are iid Gumbel, independently of the size of σ, the distribution of ν_i and the distribution of ε_{i0}. If the shocks (ε_{ij}) are assumed to be iid, then they have to be Gumbel in order to satisfy the inverse parallel demands condition as we now show.

Assuming the unique attribute is price and these are symmetric, the inverse demands when there are J and $J+1$ varieties are parallel iff there exists t such that for all p then $Q(p, J) = Q(p + t, J + 1)$, that is

$$\mathbb{P}(\varepsilon_{0m} < -p + \nu_m(1 - \sigma_m) + (\sigma_m) \max_{1 \leq j \leq J} \varepsilon_j) = \mathbb{P}(\varepsilon_{0m} < -p + t + \nu_m(1 - \sigma_m) + (\sigma_m) \max_{1 \leq j \leq J+1} \varepsilon_j).$$

Since ε_{0m} and $\nu_m(1 - \sigma_m)$ are independent of $\max_{1 \leq j \leq J} \varepsilon_j$ this can only be true if the distribution of the maxima is the same, that is

$$\max_{1 \leq j \leq J} \varepsilon_j \quad \stackrel{d}{=} \quad t + \max_{1 \leq j \leq J+1} \varepsilon_j$$

Let F be the cdf of ε, then the equation above implies there exist $t(n)$ such that for all x:

$$F(x) = F^n(x + t(n)).$$

Iterating on both sides implies

$$F^{nm}(x + t(nm)) = F^{nm}(x + t(n) + t(m))$$

we recognize an instance of Hamel's functional equation $t(nm) = t(n) + t(m)$ which has solution $t(n) = c \log(n)$.[43] Therefore:

$$F(x) = F^y(x + c \log y),$$

letting $s = c \log y$, we get $F(0) = F^{e^{s/c}}(s)$, and so:

$$F(s) = e^{\log F(0) e^{-s/c}},$$

which is a Gumbel distribution with location parameter $c \log \log F(0)$ and dispersion parameter c.

[43]It is easy to extend the formula for real numbers through rationals, note

$$F(x) = F^n(x + t(n)) = F^m(x + t(m))$$

implies

$$F(x) = F^{n/m}(x + t(n) - t(m)),$$

so we can consistently define $t(n/m) = t(n) - t(m)$.

Proof of Theorem 2

Proof. Let the random utility shocks $(\sigma\varepsilon_j)$ be iid and distributed according to F in the domain of attraction of the Gumbel distribution. Let $G(x) = exp[-exp(-x)]$ be the Gumbel distribution. Then there exist sequences (a_n, b_n) such that

$$F^n(a_n x + b_n) \to G(x),$$

Furthermore, $\lim_{n\to\infty} \frac{a_n}{a_{[nt]}} = 1$ and $\lim_{n\to\infty} \frac{b_n - b_{[nt]}}{a_{[nt]}} = -c\log(t)$ for any $t > 0$ and some $c \in \mathbb{R}$ where $[nt]$ is the integer part of nt (see Resnick (1987) Chapter 1). Since the convergence $F^n(a_n x + b_n) \to G(x)$ is uniform (see Resnick (1987) Chapter 0) and F^n is uniformly continuous, then for any $\epsilon > 0$ there exists δ and $N(\delta, \epsilon)$ such that for all $x \in \mathbb{R}$ and all $J, K > N(\delta, \epsilon)$ we have $\left|\frac{a_K}{a_J} - 1\right| \leq \delta$ and

$$\left|F^J(a_J x + b_J) - F^K(a_J x + b_K)\right| \leq \left|F^J(a_J x + b_J) - F^K(a_K x + b_K)\right| + \left|F^K(a_K x + b_K) - F^K(a_J x + b_K)\right| < \epsilon$$

Therefore, for any $p \in \mathbb{R}$

$$\begin{aligned}|Q(p, J) - Q(p + b_K - b_J, K)| &= \left|\mathbb{P}\left(\max_{j\in\{1,\dots,J\}} u_{ij}(p) > u_{i0}\right) - \mathbb{P}\left(\max_{j\in\{1,\dots,K\}} u_{ij}(p + b_K - b_J) > u_{i0}\right)\right| \\ &= \left|\int_{\mathbb{R}} \left(F^K(\eta_0 - \alpha(y-p) - \delta + b_K - b_J) - F^J(\eta_0 - \alpha(y-p) - \delta)\right) f_0(\eta_0) d\eta_0\right| \\ &< \epsilon\end{aligned}$$

where f_0 is the probability density of $\eta_0 = u_{i0} - (1-\sigma)\nu_i$. We conclude that the inverse aggregate demands are asymptotically parallel. □

Other parallel inverse demands from random utility

Without the independence assumption, there are other distributions of shocks that also give rise to parallel demands. If we do not assume independence of the shocks then the Gumbel distribution is not necessary. In this case, for any family of (downward sloping, increasing in J) parallel inverse demands there is a joint density of shocks that rationalizes it. In general, the shocks are not Gumbel and are correlated in this construction.

Observe $Q(p, J)$ can be written in terms of cdf of max shock

$$Q(p, J) = 1 - \mathbb{P}\left(\max_{j\in\{1,\dots,J\}} \varepsilon_j \leq p + \varepsilon_0\right).$$

For any family $(Q(p, J))_J$ which is decreasing in p and increasing in J, we can use inductively construct cdfs of shocks from cdf of the maximum order statistic. For example:

$$\mathbb{P}(\varepsilon_2 \leq x) = \mathbb{P}(\max\{\varepsilon_1, \varepsilon_2\} \leq x) + \mathbb{P}(\varepsilon_2 \leq x | \varepsilon_1 > x)(1 - \mathbb{P}(\varepsilon_1 \leq x))$$

where the first and third terms are fixed, but the second is free. Another way to see the construction is that basically we can let ε_2 have distribution $1 - Q(\cdot, 2)$ and be correlated with ε_1 in such a way that $\varepsilon_2 \geq \varepsilon_1$ with probability 1.

Proof of Proposition 2

Proof. As in Proposition 1, we have $\frac{\partial CS(p_1,\ldots,p_J,J)}{\partial p_j} = -q_j(p_1, \ldots, p_J, J)$, therefore considering the case where the number of products goes from J to M (with $M > J$), $\mathbf{p_J} = (p_1, p_2, ..., p_J)$ are the prices for the existing J products, and $(p_{J+1}, \ldots, p_M)$ are the prices at which the new $M - J$ products are introduced. Let $\mathbf{p_M} = (p_1, \ldots, p_M)$ and $\mathbf{p'_M} = (\mathbf{p_J}, \infty, \ldots, \infty)$ then evaluating the line integral:

$$\begin{aligned} \Lambda &= CS(\mathbf{p_M}, M) - CS(\mathbf{p_J}, J) = CS(\mathbf{p_M}, M) - CS(\mathbf{p'_M}, M) \\ &= \textstyle\int_0^\infty \sum_{j=J+1}^M q_j(\mathbf{p_J}, p_{J+1} + s, p_{J+2} + s, \ldots, p_M + s) ds \end{aligned}$$

□

Theorem 3: Robustness to uniform price changes

Observe we defined $\mathbf{p}_M^1 = \mathbf{p}_M + s\mathbf{1_M}$, this is equivalent to assuming that all prices adjust uniformly after the introduction of the new varieties. When this is not the case, let $\mathbf{v} = \mathbf{p}_M^1 - \mathbf{p}_M$ and observe for some $s \in [\min v_j, \max v_j]$ then $Q_M(\mathbf{p}_M + s\mathbf{1_M}) = Q_M(\mathbf{p}_M^1)$. Therefore

$$d = \left(\frac{\Delta P}{\Delta Q} - \left. \frac{dP}{dQ_J} \right|_J \right) \Delta Q + o\left((s - d)^2 \right) \tag{23}$$

still holds for $\Delta P = s$. Furthermore, in practice it is easy to approximate s by the average price change $\frac{1}{M} \sum_{j=1}^M v_j$. In this sense the sufficient statistics formula is robust to the assumption of long-run uniform pass-through.

However, the assumption of short-run uniform pass-through is crucial, since we use it to calculate the directional derivative $\left. \frac{dQ_J}{dP} \right|_J = \frac{dQ(\mathbf{p_J} + t\mathbf{1_J})}{dt} = \sum_{j=1}^J \frac{\partial Q_J}{\partial p_j}$.

Extension: Probabilistic Entry

In this section, we extend the symmetric firm model to allow for probabilistic entry.[44] We assume that nature draws a fixed cost. Let the equilibrium price and quantity functions be given respectively by $p(J)$ and $q(J)$. Assume that for every draw of the fixed cost, there is a uniquely determined number J of firms that enter the market. Then the distribution of fixed costs determines an equilibrium distribution F of variety J and consumer surplus from an ex ante perspective is given by:

$$CS = \int \int_p^\infty Q(s, J) ds dF(J) \tag{24}$$

Moreover, when there is an exogenous change in variety from the distribution F_1 to F_2 we may calculate, for the discrete case, that the variety effect is:

$$\Lambda = \int \int_p^\infty Q(s, J) ds dF_2(J) - \int \int_p^\infty Q(s, J) ds dF_1(J) \tag{25}$$

Suppose there exists $d(J_2, J_1)$ such that $Q_{J_2}(p + (s + d(J_2, J_1)) = Q_{J_1}(p)$ for all s. Let the conditional distribution of new variety be given by $F_{2|1}(J_2|J_1)$. Then,

$$\begin{aligned}
\Lambda &= \int \int \left[\int_p^\infty Q(s, J_2) ds - \int_p^\infty Q(s, J_1) ds \right] dF_{2|1}(J_2|J_1) dF_1(J_1) \\
&= \int \int \left[\int_0^{d(J_2, J_1)} Q(p + s, J_2) ds \right] dF_{2|1}(J_2|J_1) dF_1(J_1) \\
&= \int \int \left[\int_0^{d(J_2, J_1)} Q(p - d(J_2, J_1) + s, J_1) ds \right] dF_{2|1}(J_2|J_1) dF_1(J_1) \\
&\approx \int \int d(J_2, J_1) dF_{2|1}(J_2|J_1) Q(p, J_1) dF_1(J_1) \\
&= E[d(J_2, J_1) * Q(p, J_1)].
\end{aligned}$$

Thus, we obtain the familiar formula for the variety effect in terms of the product of the aggregate demand and the expected vertical shift of the inverse demand, the second of which

[44] In light of proposition 1 everything that follows goes through for both the continuous and discrete choice models.

is the average change in willingness to pay. Similarly, letting the bars denote expectations:

$$
\begin{aligned}
d\bar{Q} &= E_{F_2}(Q(p(J), J) - E_{F_1}(Q(p(J), J)) \\
&= E_{F_2}(Q(p(J) + d(J, J_0), J_0) - E_{F_1}(Q(p(J) + d(J, J_0), J_0)) \\
&\approx E_{F_2 - F_1}\left[\frac{\partial Q}{\partial p}(p_0, J_0) * (p(J) + d(J, J_0) - p_0)\right] \\
&= \frac{\partial Q}{\partial p}(p_0, J_0) E_{F_2 - F_1}(p(J) + d(J, J_0)) \\
&= \frac{\partial Q}{\partial p}(p_0, J_0)(d\bar{p} + E(d)).
\end{aligned}
$$

Therefore $E(d) = \left(\frac{dp}{dQ}|_J - \frac{d\bar{p}}{d\bar{Q}}\right) d\bar{Q}$ corresponds to the probabilistic version of expression (12).

Identification of the Variety Effect Using Instrumental Variables

We consider how one may usefully empirical implement our sufficient statistics formula for the variety effect. To fix ideas, consider the following econometric model for consumer surplus:

$$
CS_i = \alpha + \beta J_i + \gamma P_i + \epsilon_i \tag{26}
$$

where each i is a market and the variety effect is given by $\beta = \frac{\partial CS}{\partial J}$. First, note that consumer surplus is not observed and is not even identified in the class of parallel inverse demand models, however as far as the variety effect goes, theorem 3 shows that it is the same for all models. Therefore we can substitute CS for a representative model in (26) to identify β. If aggregate demands are linear then $CS(P, J) = \frac{dP}{dQ}\Big|_J \frac{Q^2}{2} = S * \frac{Q^2}{2}$ where S is a constant.

Second, J and P are endogenous variables (for the same reason price is endogenous in any simultaneous equation model) because consumer surplus is a function of demand, for example if ϵ captures positive shocks in preferences we can expect it to be correlated with price and variety. Therefore we need a supply shifter that is uncorrelated with ϵ to identify β.

Imagine we have the following instruments (uncorrelated with ϵ) based on sales taxes, the first is τ_1 which is the difference in tax rates in the current period relative to the previous period, and which we assume is correlated with P but not J because entry and exit of firms is not instantaneous. The second instrument τ_2 is just the tax rate and is correlated with both P and J.

The price coefficient is then $\gamma = \frac{Cov(CS,\tau_1)}{Cov(p,\tau_1)}$ and the variety effect is identified as:

$$\begin{aligned}
\beta &= \frac{Cov(CS,\tau_2) - Cov(CS,\tau_1)\frac{Cov(p,\tau_2)}{Cov(p,\tau_1)}}{Cov(J,\tau_2)} \\
&= \frac{\frac{dCS}{d\tau_2} - \frac{dCS}{d\tau_1}\frac{\frac{dp}{d\tau_2}}{\frac{dp}{d\tau_1}}}{\frac{dJ}{d\tau_2}} \\
&= \frac{S * Q * \frac{dQ}{d\tau_2} - S * Q * \frac{dQ}{d\tau_1}\frac{\frac{dp}{d\tau_2}}{\frac{dp}{d\tau_1}}}{\frac{dJ}{d\tau_2}} \\
&= Q \left.\frac{dP}{dQ}\right|_J \left[\frac{dQ}{d\tau_2} - \frac{dQ}{d\tau_1}\frac{\frac{dp}{d\tau_2}}{\frac{dp}{d\tau_1}}\right]\frac{1}{\frac{dJ}{d\tau_2}}
\end{aligned}$$

where the reduced form $\frac{dCS}{d\tau} = S * Q * \frac{dQ}{d\tau}$ (from $Cov(CS,\tau) = S * Q * Cov(Q,\tau)$) is valid for any model with parallel inverse demands and the slope of demand $\left.\frac{dP}{dQ}\right|_J = \frac{\frac{dp}{d\tau_1}}{\frac{dQ}{d\tau_1}}$ is also identified using the first instrument.

Finally, the identification of the variety effect is global to any market but local to marginal firms in each market. Observe that as long as changes in the tax rate affects J and P in any market, we are estimating an Average Treatment Effect (ATE). However, if instead of J we look at individual firms' binary decision to enter or not a market then the instrument only affects marginal firms, in that sense the variety effect that is identified is local to marginal firms, which are the only ones responding to exogenous shocks.

The Principle of Le Chatelier and Externalities

A concern with using short-run and long-run price elasticities of demand to identify the variety effect is that differences between the two may conflate changes in the level of variety with changes that might occur for other reasons. In this section, we extend the model by incorporating an outside market represented by the variable y and we assume the consumer can only adjust y in the long run and the firms can only adjust p_y in the long run. We start from a continuous choice model where all firms in the inside market are symmetric, we denote p the symmetric equilibrium price of the inside market, and Q the aggregate quantity.

Let $u(Q,y,J) - pQ - p_y y$ be the utility function of the consumer and assume u is supermodular and quasiconcave. Let

$$Q^*(y,p,p_y,J) = \underset{Q}{\text{argmax}}\, u(Q,y,J) - pQ - p_y y$$

be the aggregate demand of the inside good conditional on (p, y, J), and let

$$y^*(p, p_y, J) = \underset{y}{\operatorname{argmax}}\, u(Q^*(y, p, J), y, J) - pQ^*(y, p, J) - p_y y$$

be the optimal choice of y given $(p, p_{y,} J)$. Finally, define the long-run aggregate demand $Q(J) = Q^*(y^*(p(J), p_y(J), J), p(J), p_y(J), J)$.

Observe the long-run change in aggregate demand for the inside market given an exogenous change in variety J has three components:

$$\frac{dQ(J)}{dJ} = \frac{\partial Q^*}{\partial p}\frac{dp(J)}{dJ} + \frac{\partial Q^*}{\partial p_y}\frac{dp_y(J)}{dJ} + \frac{\partial Q^*}{\partial y}\frac{dy(p(J), p_y(J), J)}{dJ} + \frac{\partial Q^*}{\partial J} \tag{27}$$

the indirect effect of variety through equilibrium price p, the indirect effect of variety through the outside variable y, and the direct effect of variety J.

Assume the following parallel inverse demands condition:

Assumption. *(Parallel Inverse demands) For all J and all y there exists d such that for all p then $Q(y, p, p_{y,} J) = Q(y_{0,} p + d, p_{y0}, J_0)$.*

As before we can calculate the vertical shift

$$d \approx \left(\frac{dp}{dQ^*} - \frac{dp}{dQ}\right) * dQ. \tag{28}$$

Define the indirect utility function

$$w(y, p, p_y, J) = u(Q^*(y, p, p_y, J), y, J) - pQ^*(y, p, p_y, J) - p_y y$$

and note from the consumer perspective in a long-run equilibrium welfare is

$$v(J) = w(y^*(p(J), p_y(J), J), p(J), p_y(J), J).$$

Taking the first-order conditions:

$$\begin{aligned}
\frac{dv(J)}{dJ} &= \frac{\partial w}{\partial y}\frac{dy^*}{dJ} + \frac{\partial w}{\partial p}\frac{dp}{dJ} + \frac{\partial w}{\partial p_y}\frac{dp_y}{dJ} + \frac{\partial w}{\partial J} \\
&= \frac{\partial w}{\partial y}\frac{dy^*}{dJ} - Q\frac{dp}{dJ} + \frac{\partial w}{\partial p_y}\frac{dp_y}{dJ} + \Lambda \\
&= -Q\frac{dp}{dJ} + \frac{\partial w}{\partial p_y}\frac{dp_y}{dJ} + \Lambda
\end{aligned}$$

where the last line follows from the envelope theorem. Furthermore, the parallel inverse demands condition implies $-Q * d \approx \left(\Lambda + \frac{\partial w}{\partial p_y}\frac{dp_y}{dJ}\right) dJ$ and so

$$dv(J) \approx -Q * (dp + d). \tag{29}$$

In other words, we can estimate the welfare effect in (29) by estimating pass-through (dp) and the vertical shift parameter (d) through equation (28). To estimate the latter, we need the short-run slope of demand (keeping both variety J and the outside market demand y fixed) and the long-run slope of demand when both y and J are adjusted. However, estimating the vertical shift parameter is not enough to estimate the variety effect, Λ, since the vertical shift includes indirect effects of variety through the outside market price p_y. An application of the Le Chatelier Principle (Samuelson 1947, Milgrom and Roberts 1996) shows the slope of demand in the very long run (when both J and p_y are adjusted) is steeper than when only variety J adjusts, therefore $-Q * d$ would be overestimating Λ. In summary, the love for variety assumption and the Le Chatelier Principle together imply the following bounds:

$$0 \leq \Lambda \leq -Q * d'(J).$$

We have shown how to apply the parallel demands assumption in a model with an outside market y to calculate the welfare effect $\frac{dv}{dJ}$ with the reduced-form estimates that are analogous to those used in the baseline model. If we are interested in calculating the variety effect Λ we need one more estimate: the long-run slope of demand where J is variable but p_y is kept constant $\left.\frac{dQ}{dJ}\right|_{p_y} = \frac{dQ^*(y,p(J),p_y,J)}{dJ}$. Then

$$\Lambda = Q * \left(\frac{\frac{dp}{dJ}}{\left.\frac{dQ}{dJ}\right|_{p_y}} - \frac{1}{\frac{\partial Q^*}{\partial p}} \right) * \left.\frac{dQ}{dJ}\right|_{p_y}.$$

To put diferently, if in the long run the price of the outside market p_y is correlated with J, the variety effect is not identified with the two instruments we described and in that case we need an instrument which is uncorrelated with p_y. However, it is important to notice, that y has no direct effect on welfare given the envelope theorem $\frac{\partial w}{\partial y} = 0$, so only changes in the price p_y (which are not controlled by the consumer) affect the estimation of Λ.

Applications

We now consider several applications of our model. First, we revisit the classic question of whether free-entry is efficient and show how one can shed light on this question using reduced-form empirical methods. Second, we consider the marginal welfare gain or loss of a small tax change in the context of product variety and show to empirically implement it. We begin by describing firms, market structure and the government.

Firms and Government

We start by assuming each firm j produces a single product according to the cost function $c_j(q_j) = c(q_j) = cq_j + f$ which is identical for all firms.[45] Each firm faces an valorem tax on its output τ. A given firm makes two decisions. First, each firm decides whether to enter the market given a fixed cost of entry. Second, each firm chooses p_j to maximize profits:

$$\max_{p_j} \pi_j = p_j(1-\tau)q_j(p_1 \ldots, p_J) - cq_j(p_1 \ldots, p_J) - f$$
$$\text{s.t. } \frac{\partial p_k}{\partial p_j} = \vartheta \text{ for } k \neq j.$$

The first-order condition for p_j is given by

$$(1-\tau)q_j + (p_j(1-\tau) - c)\left(\frac{\partial q_j}{\partial p_j} + \sum_{k \neq j} \frac{\partial q_j}{\partial p_k}\frac{\partial p_k}{\partial p_j}\right) = 0.$$

We allow for different forms of behavior by letting $\frac{\partial p_k}{\partial p_j} = \vartheta$, for $k \neq j$, parametrize the degree of competition. For example, by setting $\vartheta = 0$ we obtain Bertrand competition and setting $\vartheta = 1$ we obtain perfect collusion. This is related to the way Weyl and Fabinger (2013) model competition, although they focus on tax incidence and pass-through with a fixed number of firms.[46] The conjectural variation terms only make sense when they correspond to static solution concepts or are reduced forms of truly dynamic models (see Vives 2001, Riordan 1985) or supply function equilibria (Hart 1982). We do not take a stance on which is the dynamic model that ϑ captures in reduced form, instead proving that our evaluation of welfare is robust to any of the specifications that can be modeled this way.

In a symmetric equilibrium, $p_1 = p$ solves:

$$(1-\tau)q_1(p_1, p, \ldots, p) + (p_1(1-\tau) - c)\left(\frac{\partial q_1(p_1, p, \ldots, p)}{\partial p_1} + (J-1)\vartheta\frac{\partial q_1(p_1, p, \ldots, p)}{\partial p_2}\right) = 0.$$

[45]One can define a more general cost function $c(q) + f$ for a convex variable cost function $c(q)$ and all the results go through.

[46]In the homogeneous good conjectural variations model, the first order condition is given by

$$p(1-\tau) + \frac{dp(1-\tau)}{dQ}(1+\theta) - c = 0$$

where $1 + \theta \equiv \frac{dQ}{dq}$. The model nests various forms of competition such as Cournot ($\theta = 0$), Bertrand ($\theta = -1$), and perfect collusion ($\theta = J - 1$) which, of course, gives the monopoly outcome.

We assume the left hand side $\frac{\partial \pi_1}{\partial p_1}(p_1, p)$ is strict single crossing (from above) in p_1 and decreasing in p so that a unique symmetric equilibrium $p(J, \tau)$ exists.[47] Furthermore, we require that $\pi_j(p(J, \tau), J, \tau)$ be decreasing in J. Then, the "long run" number of firms J^* is determined by the free-entry condition $\pi_j(p(J^*, \tau), J^*, \tau) = 0$:

$$p(J, \tau)(1 - \tau)q(p(J^*, \tau)) - cq(p(J^*, \tau)) - f = 0. \tag{30}$$

Finally, government revenue is given by $R = \tau * p * Q$ and social welfare W is defined as the sum of consumers' surplus (CS), producers' surplus (PS) and government revenue (R).

Socially Optimal Product Variety

It is a well-known result that the number of firms in a free-entry equilibrium, may diverge from the socially optimal number of firms (Spence 1976a, Spence 1976b, Dixit and Stiglitz 1977, Mankiw and Whinston 1986, Anderson, de Palma and Nesterov 1995). Observe the marginal welfare gain of variety is given by:

$$\frac{\partial W}{\partial J}(J(\tau), \tau) = \Lambda + \pi + \tau pq + (p - c)J\frac{\partial q}{\partial J}. \tag{31}$$

The private optimum is determined by equation (30), where free entry drives profits to zero; thus, we see that the private and social optimum diverge whenever $\Lambda + \tau pq + (p - c)J\frac{\partial q}{\partial J} \neq 0$. The first term is the variety effect and reflects the fact that firms create consumer surplus when they enter, a value which they may not completely internalize if they cannot extract all surplus. The second effect is the gain in government revenue which is a second externality not internalized by firms. Finally, the last term is the business-stealing effect which arises because entry affects output per firm, if q increases then entry is business enhancing otherwise entrants are stealing business from incumbent firms, in any case there is an externality imposed to the other firms (Mankiw and Whinston 1986). If the number of firms in the free-entry equilibrium diverges from the social optimum it depends on the relative size of the positive and negative externalities, starting from a benchmark without taxes ($\tau = 0$), socially optimal variety is determined by balancing the variety effect with the business-stealing effect.

Empirical Implementation. In general, theory cannot determine where $\frac{dW}{dJ} \gtreqless 0$. Thus, whether there is excessive or insufficient entry is an empirical question. There have been some attempts to tackle this question in the literature (Berry and Waldfogel 1999, Berry, Eizenberg and Waldfogel 2015). These papers mostly consider a structural approach by specifying the

[47] The case of strategic complementarities, where $\frac{\partial \pi_1}{\partial p_1}(p_1, p)$ is increasing in p allows for the existence of multiple symmetric equilibria, in that case assume there is a continuous and symmetric equilibrium selection $p(J, \tau)$.

utility function and the nature of firm competition. In this paper, we pursue a complementary approach. We show that one may use *exogenous* variation in variety entry to identify whether there is too little or too much variety. Ignoring government revenue effects, the logic is straightforward: with an exogenous change in J we can use Theorem 1 to identify Λ. The key challenge is identifying the business-stealing term $(p-c)J\frac{\partial q}{\partial J}$. Although $\frac{\partial q}{\partial J}$ is estimable, one requires a measure of the social value of this output, $p-c$.[48] It turns out that this can be pinned down by a price effect using a free-entry envelope condition.

To fix ideas, consider a cost shifter, τ. In general, any cost shifter is valid, but we focus on taxes since this is the empirical application we consider below. The reduced-form objects we focus on are the short-run and long-run price effects, output effects and variety effects. First, we note that the variety effect can be pinned down as follows:

$$\Lambda = -Q\left[\left.\frac{dp}{d\tau}\right|_J \frac{\frac{dQ}{d\tau}}{\left.\frac{dQ}{d\tau}\right|_J} - \frac{dp}{d\tau}\right]\frac{1}{\frac{dJ}{d\tau}} \tag{32}$$

The intuition for the variety effect is illustrated in Figure 4. Here we consider a small increase in taxes. As discussed above, the base of the rectangular area is given by pre-existing output before the tax change. The height of the rectangle is given by the difference between "long-run" change in price as a result of the tax change and the "short-run" change in price re-scaled by the ratio of the long-run output effect to the short-run output effect of the tax. The re-scaling serves to extend the price effect up the demand curve so that it's measured at the long-run output level. The identification of the variety effect thus comes from a policy instrument that shifts marginal costs (such sales taxes), and is observed in a setting where variety is held constant and in a setting where variety can respond endogenously to the policy change, subject to a free entry condition. In the case of a standard CES demand model, both of the short-run and long-run effects are linked together by a single elasticity parameter. What our framework highlights is that in order to separately identify the demand elasticity (holding variety constant) from the variety effect, one requires two separate sources of variation. Conceptually, one needs an instrument to trace out demand holding variety constant and an instrument for variety. Practically, finding plausibly exogenous shocks to variety is likely to be challenging. Therefore, instead, we trace out the "long run" demand curve that allows both prices and variety to respond to cost shifter and show that this can be combined with the "short run" demand curve to identify the variety effect.

With the variety effect in hand, we next consider the business-stealing effect. Totally

[48] If the consumer price and producer price are equal, this is also the firm's markup.

differentiating the free-entry condition with respect to the tax, one can solve for $p - c$ and show that:

$$(p-c)J\frac{\partial q}{\partial J} = \frac{\frac{d(\tau pQ)}{d\tau} - Q\frac{dp}{d\tau} - \tau pq\frac{dJ}{d\tau}}{\frac{dQ}{d\tau} - q\frac{dJ}{d\tau}} \frac{\frac{dQ}{d\tau} - q\frac{dJ}{d\tau} - \frac{dQ}{d\tau}|_J}{\frac{dJ}{d\tau}} \tag{33}$$

This condition shows that we can recover the business-stealing effect using the short-run and long-run effects of the tax on firm output, prices, and firm expenditures. To see the intuition for this expression, note that if the zero profit condition holds before and after the policy change, then

$$-(p(1-\tau)-c)\frac{dq}{d\tau} = q\frac{d(p(1-\tau))}{d\tau}$$

Thus, if there is a business-stealing effect so that per-firm output goes down in response to the policy reform $\left(\frac{dq}{d\tau} < 0\right)$, in a long-run equilibrium, these losses have to be offset by higher revenue in the form of higher per-unit prices. By re-arranging this condition, we get $p - c = \frac{-q\frac{dp}{d\tau} + \frac{d(pq\tau)}{d\tau}}{\frac{dq}{d\tau}}$, which is the first term in equation (33). The second term follows naturally from the fact that $q = q(J(\tau), \tau)$ and $\frac{dQ}{d\tau} = q\frac{dJ}{d\tau} + J\frac{dq}{d\tau}$. Note that we do not require direct estimates of costs and markups which may be difficult to measure in practice. By comparing the estimated variety effect and business-stealing effect, we can determine whether there is too little or too much variety.

A key advantage of our framework is that it illustrates in a transparent way the reduced-form estimates that are needed to conduct a welfare analysis. In this sense, our framework is broadly related to the recent work on sufficient statistics (e.g., Chetty 2009), and we show how the welfare analysis of product variety can be implemented using a key set of estimable reduced-form parameters. Conditional on these statistics, the researcher does not need to estimate additional structural parameters governing consumer tastes or firm costs, which may give our approach an advantage of robustness to misspecifying these aspects of the problem. As a result, it is relatively straightforward to implement, which makes it applicable to the settings studied in IO, Public Economics and Trade.

Marginal Welfare Gain or Loss of a Tax Change

We consider a government that imposes an ad-valorem tax (τ) on each product in the market (but not the outside good). This generates revenue $R = \tau pQ$. Welfare is defined as $W = CS + PS + R$ where CS and PS are aggregate consumer and producer surplus, respectively. The marginal welfare gain is:

$$\frac{dW}{d\tau} = \frac{dCS}{d\tau} + \frac{dPS}{d\tau} + \frac{dR}{d\tau} \tag{34}$$

First, consider the case of competitive pricing $p(1-\tau) = c$ and socially optimal variety (given the tax τ and given competitive pricing) for all m. In this case, the marginal welfare gain from increasing the tax rate τ is $\frac{dW}{d\tau} = \tau p \left.\frac{dQ}{d\tau}\right|_J$.[49] Next, assume pricing decisions are left to firms and variety can be set optimally by the government, given the taxes (τ) and given firms' pricing decisions. The marginal welfare gain from increasing the tax is $\frac{dW}{d\tau} = (p-c) \left.\frac{dQ}{d\tau}\right|_J$.[50] Finally, assume that firms control both pricing and entry decisions. The marginal welfare gain becomes:

$$\frac{dW}{d\tau} = (\Lambda - f)\frac{dJ}{d\tau} + (p-c)\frac{dQ}{d\tau} \tag{35}$$

To see the intuition for this, consider the case where $\Lambda = 0$ which corresponds to homogeneous products.[51] We see that the new term added to the welfare formula is $-f\frac{dJ}{d\tau}$. In this case, a tax cut leads to inefficient entry since the new output produced as a result of the tax could have been produced more cheaply by incumbent terms. The only modification when there is product variety is that entry might not be inefficient if consumers place a sufficiently high value on the new products.[52]

Empirical Implementation The above expressions do not make use of the free-entry condition and may be difficult to implement empirically since they require estimates of firms' costs and markups. When the free-entry condition holds before and after the policy change the marginal firm $J(\tau)$ earns zero profits. In the symmetric model this implies that producer surplus $PS = J\pi = 0$ before and after the policy change. To derive a condition that is more easily implementable, we impose the assumption that after a tax change, profits are driven to zero to show that the long-run welfare gain from marginally increasing taxes is:[53]

$$\frac{dW}{d\tau} = -Q\left.\frac{dP}{d\tau}\right|_J \frac{\frac{dQ}{d\tau}}{\left.\frac{dQ}{d\tau}\right|_J} + PQ + \tau\frac{d(PQ)}{d\tau} \tag{36}$$

To implement the marginal welfare gain in (36), we only require behavioral responses to taxes. In particular, we do not need to estimate the distribution of random utility shocks, the

[49]See Harberger (1964), Chetty (2009)

[50]See Auerbach and Hines (2001).

[51]This is considered in Besley (1989) and Auerbach and Hines (2001). Although these papers consider Cournot competition, our formulas are valid for a broader class of models.

[52]One can also show the following equivalent representation for the marginal welfare gain: $\frac{dW}{d\tau} = (\Lambda + \pi + \tau pq)\frac{dJ}{d\tau} + (p-c)J\frac{dq}{d\tau}$.

[53]In a model with asymmetric firms, we do not need to assume $PS = 0$ before and after the policy change, rather we would require $\frac{d\pi_j}{d\tau} = 0$ to get a similar formula. This is equivalent to $-(p_j(1-\tau) - c'(q_j))\frac{dq_j}{d\tau} = q_j\frac{d(p_j(1-\tau))}{d\tau}$, the condition we used to estimate markups in the previous section.

fixed cost of entry f, the marginal cost of production c, or the market conduct parameter θ.

The empirical setting we consider below is about consumption of grocery products. Our data contains a classification which assigns products to "modules", which we may interpret as nests through the lens of our model. Here we briefly sketch out a more general model where each product belongs to a nest, $m \in M$, where we take the nesting structure as exogenous. This modeling structure closely follows Sheu (2014). Products within a nest are taken to be more substitutable than products between nests. We assume that expenditures are exhausted across all grocery store products. Thus, while the random utility model considered above defined the "reference good" as the no purchase option, in this model, we assume that the outside option of not purchasing a product in some nest is choosing the most preferred option among products in all other nests. Thus, any effects of changing expenditures in a given nest would be captured by shifting expenditures to a different nest. In this setting, some nests are subject to taxes and other nests are not. We denote the set of taxable nests as M_T.

$$\frac{dW}{d\tau} = \sum_{m=1}^{M} \left(\Lambda_m \frac{dJ_m}{d\tau} - Q_m \frac{dp_m}{d\tau} \right) + \sum_{n \in M_T}^{M} \frac{d(\tau p_n Q_n)}{d\tau}. \tag{37}$$

The first term shows that one needs to evaluate the effect of the tax on variety and prices in all nests. The second term shows that one needs to consider the fiscal externality which only requires measuring behavioral responses in taxable nests. Under two assumptions, we can retrieve the marginal welfare gain in (36). First, we assume symmetry within M_T and within $M \backslash M_T$. Second, we assume that prices, quantity and variety in untaxed nests do not respond to taxes.

Online Appendix: Empirical Analysis

Nielsen Retail Scanner Data

We obtained the Nielsen scanner data from the Kilts Marketing Data Center at the University of Chicago Booth School of Business. The micro data records weekly prices and quantities by product at the barcode level (Universal Product Code, UPC) for over 35,000 stores from approximately 90 retail chains across the United States (except for Hawaii and Alaska), covering the years 2006-2014.[54] Each store, geolocated at the county level, is assigned one of

[54] Products without a barcode such as random weight meat, fruits, and vegetables are not included in the data set.

five possible store types ("channels"), and can be matched with its parent chain.[55] Products are organized in a hierarchical structure: There are over 2.5 million different UPCs, which are categorized into approximately 1,200 *product-module*s. Each module is then assigned to one of roughly 120 *product-groups*, which in turn is part of one of 10 broader *product-departments*. Table A1 shows a few examples of UPCs included in the retail data.

The Retail Scanner dataset's coverage of total U.S. sales volume varies across locations and store-types. For instance, it covers more than half of the total sales volume of U.S. grocery stores, but only 2 percent of sales in convenience stores. Also, the distribution of stores by store-type varies substantially across locations. Therefore, to address any potential bias caused by differential coverage of sales by type of products across counties, we collapse the data at the store-level rather than at the county-level and exploit within-store variation in our analyses. We further impose several sample restrictions. First, we restrict our sample of stores to grocery stores to ensure that compositional differences across regions are not driving our results. Second, we only keep modules sold in all 48 continental states. Finally, in our main specification, we restrict the sample to the top selling modules that rank above the 80th percentile of total U.S. sales in the distributions of food and non-food modules. These modules account for almost 80% of the total value of sales in grocery stores in the scanner data.

From the scanner data, we construct two samples that we use for our empirical analysis: 1) repeated cross-sections where the unit of observation is at the store-module-year level, 2) panel data where the unit of observation is at the store-module-quarter level. For each sample, we generate measures of price (p), expenditure (pQ) and product variety (J) at the module level. All of our regressions are based on expenditures, not output.

Prices To measure price for each module-store-period combination, we take several steps. First, we average (pre-tax) prices across weeks to obtain either quarterly or yearly measures:

$$p_{jmrt} = \frac{\sum_{w \in t} (q_{jmrw} \times p_{jmrw})}{\sum_{w \in t} q_{jmrw}}.$$

where j = UPC, m = module, r = store, and w = week. Formally, q_{jmrw} denotes the number of units of product (UPC) j in module m sold in store r, located in county c in state s, in week w. Similarly, p_{jmrw} is the associated per-unit average weekly price. Second, we

[55] The five channels are grocery, drug, mass merchandise, convenience and liquor stores. Each store and each parent chain has a unique identifier. Retail chain names are confidential and unknown to researchers.

average prices across UPCs to obtain module-level price indices. Handbury and Weinstein (2015) show that comparing standard indices across locations can be problematic if consumer preferences are heterogeneous across locations, and if some varieties are unavailable in some places. For example, if consumers in a given location tend to buy larger packages of a given beverage than in other locations, the average *per-unit* price will be higher in that location even though the *per liter* average price is likely lower. To correct for these sources of bias, we follow Handbury and Weinstein (2015) and adjust prices by estimating the following regression separately for each module:

$$\log p_{jmrt} = \alpha_j + \alpha_{mrt} + \varepsilon_{jmrt}$$

where α_j and α_{mrt} are UPC and module-store-time fixed effects, respectively.[56] We keep the estimated module-store-time fixed effects, $\hat{\alpha}_{mrt}$ as pre-tax price indices (which are in logs). Adjusted consumer prices are then given by $\tilde{p}_{mrcst} = \exp(\hat{\alpha}_{mrt} + \log(1 + \tau_{mcs}))$ where c = county and s = state.

We then normalize the consumer price indices within store-time cells by dividing by the store-time-specific average *pre-tax* price.[57] Note that we normalize using pre-tax prices rather than consumer prices so that the *mechanical* relationship between the price measure and sales taxes is effectively one-to-one. To see this, note that $\log(\tilde{p}_{mrcst}/\bar{p}_{mrcst}) = \hat{\alpha}_{mrt} + \log(1+\tau_{mcs}) - \log \bar{p}_{mrcst}$.

Expenditures To measure expenditures, we aggregate revenue across all UPCs to the module-store-year level for the cross-sectional analysis and to the module-store-quarter level for the time-series analysis. We denote weekly revenue from sales of product j in store r by $R_{jmrw} = q_{jmrw} \times p_{jmrw}$ and module-level measures are obtained by aggregating across UPCs and weeks: $R_{mrt} = \sum_{j\in m}\sum_{w\in t} R_{jmrw}$. The unit of time, t, is either a year (for equation (39)) or a quarter (for equation (41)). Finally, we calculate expenditure *shares* within each store-time cells: $E_{mrt} = R_{mrt}/R_{rt}$ for each period, where $R_{rt} = \sum_m R_{mrt}$.

Variety Finally, variety is measured by counting the number of unique UPCs per module sold each period t in store r: $J_{mrt} = \{j \in J_m | q_{jmrt} > 0\}$. As for prices, we normalize variety by dividing by the store-time average.

[56] Observations are weighted by expenditures, R_{jmrt}. We run these regressions twice – once at the yearly and once at the quarterly level, for long-run and short-run specifications respectively.

[57] The within store-time average is $\bar{p}_{mrt} = \frac{1}{N_{rcst}} \sum_m \exp(\hat{\alpha}_{mrt})$, where N_{rt} is the number of modules with positive sales in store r at time t.

U.S. Sales Tax Exemptions and Rates

The second source of data we use is a hand-collected monthly panel of local (county and state) sales tax *rates* and state-level *exemptions*, which vary at the product-module level, covering the years 2006-2015.[58] All sources used to input the exemption status of products are listed in Table A9. In general, exemptions are set by states and are module-specific.[59] The general rule of thumb is that food products are tax-exempt and non-food products are taxable. However, there are important exceptions to this rule. First, several states tax food at the full rate or a reduced rate. Second, in a few states, food products are exempt from the state-level portion of the total sales tax rate, but remain subject to the county-level sales tax. Third, in some cases where food is tax-exempt, there is a tax that applies at the product-module level. For example, prepared foods are subject to sales taxes in many states. Finally, some states exempt some non-food products from sales taxes. Our final exemption sample is at the county-module-month level, however it should be noted that changes in exemptions over time are very rare during our sample period. For tax rates, we collected monthly state-level and county-level rates.[60]

There are several possible sources of measurement error in our sales tax rates. First, we do not incorporate county-level exemptions or county-specific sales surtaxes that apply to specific products or modules, although our understanding is that these cases are uncommon. Second, there may be measurement error coming from our exemption definitions and how we assigned a taxability status to each module, which in some cases required a subjective judgment based on interpreting the text of the state sales tax law. While the bulk of the variation in taxes occurs at the module level or higher, there are some instances where taxability varies within module. For example, in New York, fruit drinks are tax exempt as long as they contain at least 70% real fruit juice, but are subject to the sales tax otherwise. Therefore, some products in Nielsen's module "Fruit Juice- Apple", may or may not be taxed in New York, but all are considered eligible for the sales tax exemption in our database since we cannot readily identify the real fruit juice content.[61]

[58] We use sales tax rates from 2015 to test whether there is an anticipation response to changes in sales tax rates and do not find any evidence that there is. Results are available upon request.

[59] There are a handful of exceptions to this. Colorado, for example, allows each county to decide whether to subject food to the county-level portion of the sales tax rate.

[60] Some cities and other localities also impose an additional local sales tax rate. We do not incorporate rates that apply to areas smaller than counties.

[61] In cases where it is impossible to tell whether the majority of products in a given module are subject to the tax or not, we code the statutory tax rate as missing. This results in excluding less than 3% of the observations in our sample.

As a final step, we merge the effective sales tax rates to the Nielsen scanner data. This requires aggregating the sales tax data to the level of the scanner data. For the cross-sectional analysis, we obtain yearly sales tax rates by relying on the effective rate on September 1 of a given year.[62] For the time-series analysis, we use the rate effective at the mid-point of each quarter (February for quarter 1, May for quarter 2, etc). We then merge the sales tax rates to the scanner data by product-module, county and time. Our final cross-sectional and panel samples cover over 10,000 grocery stores, and contain price, expenditures and variety for 198 modules in 1,625 counties.[63]

Table A2 presents the tax status of the top selling food and non-food modules in our sample. There are several noteworthy observations. First, modules such as soft drinks, ice cream, and candy are taxed in states that exempt food, like Connecticut, Florida, and Wisconsin. Second, several non-food modules are exempt from taxes. For example, toilet tissue and diapers are exempt in New Jersey and Pennsylvania and magazines are exempt in Maine, Massachusetts, New York and Oklahoma. This provides an additional source of variation in tax liabilities across states which is useful for identifying the long-run effect of taxation as we discuss more fully below.

Descriptive Statistics

Figure 5 shows the cross-sectional distribution of the total sales tax rate (state + county) in September 2008. There is substantial cross-sectional variation in sales tax rates ranging from zero in Montana, Oregon, New Hampshire and Delaware to a maximum rate of 9.75 percent in Tennessee. Table A3 compares the observable characteristics of low and high tax states. It presents annual descriptive statistics for the year 2008 for simplicity as the patterns are very similar in the other years of our sample. Column (1) reports means and standard deviations for all counties and columns (2) and (3) report results for high and low sales tax counties, respectively. The typical county in our sample has roughly $75 million (U.S. dollars) in yearly grocery store sales (for the top 20 percent selling modules) with about 6.5 stores per county. Food modules account for roughly 75 percent of total annual sales on average. There are roughly 100 varieties sold in a typical module in a typical grocery store over a year. Turning to taxes, the average combined county and state sales tax rate is 6.3 percent while the average

[62] Most rate changes occur either on January 1 or July 1.

[63] The panel includes stores in 1,625 counties, but the number of stores and counties varies slightly across years.

tax rate on food products alone is 1.6 percent. Finally, the typical county has a population of about 165,000, a household median income of \$44,000 and roughly 50 percent with a high school degree or less.

Turning to columns (2) and (3), we see that grocery stores are very similar between high-sales tax and low-sales tax counties on a number of dimensions although low-tax counties have larger sales per store (\$10 million versus \$9.3 million). Locations with sales tax rates above the median exhibit lower rates of excise taxes on alcohol and cigarettes, tend to be more populous, have more grocery stores, and cover smaller territories. In column (4), we regress the county characteristics on the sales tax rate. The reported coefficients indicate that sales tax rates are negatively associated with variety and price levels, but positively correlated with the food share of sales. These regressions also provide further evidence that counties with high sales tax rate have, on average, lower rates for other types of taxes.

In Figure A1, we present visual evidence on the distribution of food tax exemptions across states. In general we see that food taxability status is spatially correlated. For example, most states that tax food are located in the South or in the Midwest. In regressions below, we evaluate the robustness of our results to controlling for module fixed effects interacted with census region fixed effects.

Empirical Models

In this section, we discuss the research design we use to study the effects of taxation. Later we discuss how we map our reduced-form empirical estimates to our sufficient statistics in order to implement our welfare formula in equation (17).

Long-Run Effects of Taxation

Suppose that food modules are exempt in all locations and non-food products are taxed everywhere, and sales tax rates are set by legislators independently of local differences in sales/prices between food and non-food products. In this case, we can recover a consistent estimate of the long-run elasticity of taxation by estimating the following difference-in-differences (DD) regression model:

$$\log y_{mrcs} = \beta^{LR} \left(\log(1 + \tau_{cs}) \times Nonfood_m\right) + \delta_r + \delta_m + \varepsilon_{mrcs} \tag{38}$$

where the outcome y_{mrcs} is either price, expenditures , or product variety . The terms δ_r and δ_m are store fixed effects and module fixed effects, respectively, $Nonfood_m$ is a dummy variable for non-food modules and τ_{cs} is the sales tax rate in county c.[64] Any county-level differences that do not vary across modules are absorbed by the store fixed effects. Any systematic differences in taxability across modules are soaked up by the module fixed effects. The coefficient of interest is β^{LR} . Under the assumptions stated above, we can use OLS to estimate the long-run causal effect of taxes on prices, expenditures, and variety.

Our preferred specification builds on the DD specification by additionally incorporating variation in tax rates across modules within the broad categories of food and non-food products. This mainly arises due to product-specific exemptions, such as the taxation of candy products in some states or the exemption of diapers. In this case, the long-run estimating equation is given by:

$$\log y_{mrcs} = \beta^{LR} \log(1 + \tau_{mcs}) + \delta_r + \delta_m + \varepsilon_{mrcs}. \tag{39}$$

The main difference between equations (38) and (39) is the definition of the sales tax rate. For the latter equation, taxes may vary across food (non-food) products within a store, hence the tax rate is also subscripted by m. The long-run parameter β^{LR} is identified under the assumption that the within-store *differences* in statutory rates across modules do not systematically vary across counties with within-store differences in unobservables. For example, our estimates of β^{LR} for expenditures would be biased upwards if jurisdictions where the consumption share of unhealthy food products (e.g., candy, soft drinks) is relatively high responded by specifically subjecting these goods to the sales tax.

Our final empirical strategy to estimate long-run effects is to implement a border-design following Holmes (1998), Dube, Lester and Reich (2010), and Hagedorn, Manovski and Mitman (2016). We restrict the sample of stores to those located in contiguous counties located on opposite sides of a state border. Two contiguous counties located in different states form a county-pair d, and counties are paired with as many cross-state counties they are contiguous with. The estimating equations are modified such that module fixed effects are now county-pair specific:

$$\log y_{mrcsd} = \beta^{LR} \log(1 + \tau_{mcs}) + \delta_r + \delta_{md} + \varepsilon_{mrcsd}. \tag{40}$$

To estimate equation (40), the original dataset is rearranged by stacking all pairs. For

[64] Note that the main effects of the $Nonfood_m$ indicator and the sales tax rate τ_{cs} are absorbed by the inclusion of module and store fixed effects in the model.

instance, a module-store cell located in county c appears as many times as the number of counties county c is paired with. Regressions are weighted by the inverse of the number of pairs a county is part of.

Short-Run Effects of Taxation

The baseline short-run specification is the following:

$$\log y_{mrcst} = \beta^{SR} \log(1 + \tau_{mcst}) + \delta_t + \delta_{mr} + \delta_m \times t + \varepsilon_{mrcst} \quad (41)$$

where the unit of time (t) is a quarter, and δ_t and δ_{mr} are quarter and module-by-store fixed effects. In some specifications, we include a module-specific time trend $\delta_m \times t$ while in others we include module-by-quarter fixed effects, δ_{mt}. The dependent variables used to estimate the elasticities of interest are normalized within store-time cells to account for module-invariant store-specific trends. The identifying assumption is that states and counties do not *differentially* change effective sales tax rates across products endogenously with respect to changes in consumer demand. Additionally, we require that any quarter-to-quarter variation in product variety is unrelated to sales tax policy changes – an assumption we test.

Empirical Results

This section reports more empirical results that are referred to in the paper.

Difference-in-Differences (DD)

We estimate the simplified DD model in equation (38) by restricting the sample to counties where food products are fully exempt from the state sales tax, and to modules that are either taxed or exempt in all stores in this subset of counties.[65]. We estimate cross-sectional regression models separately for each year between 2006 and 2014, and then take a simple linear combination of all the coefficient estimates. Our estimates are contained in Table A4 and are very similar to the baseline estimates reported in Table 1 of the paper.

[65] The selection criteria for the difference-in-differences estimation sample is based on state-level exemptions and therefore includes stores located in a handful of states where food products are exempt from the state's sales tax but may remain subject to some local taxes.

Robustness Tests: Long-Run

We explore a series of robustness checks in Table A5. Columns (1) and (2) report our benchmark results from Table 2 for comparison. First, to address spatial correlation of taxes, we turn to a specification that relies exclusively on module-specific exemptions. More precisely, we exclude all observations included in the difference-in-differences model. This sample thus includes: (a) all observations in counties where food is subject to a sales tax, as well as (b) for counties where food is generally exempt, the subset of modules for which there is some between-state variation in taxability status. The results, shown in columns (3) and (4) of Table A5, are in line with the baseline estimates. Second, we examine the robustness of our results to dropping small counties (with a population below $150,000$), for which few stores are observed and are therefore more likely to be subject to sampling issues. These are reported in columns (5) and (6) and again we find that our results are qualitatively similar. Third, to verify that the estimated effects are not driven by *counties* setting their local sales tax rates endogenously with respect to local consumer preferences, we instrument the county-level effective sales tax rate with the state-level effective rate (columns (7) and (8)) and again find similar results. Finally, in column (9), we include all Nielsen's modules that are observed in all of the 48 continental states. Our estimates are consistent across all these specifications.

Robustness Tests: Short-Run

In Table A6 we explore the sensitivity of our short-run estimates to alternative samples and specifications. Columns (1) and (2) show our baseline estimates from Table 3 for comparison. In column (3), we include store-by-time fixed effects to flexibly account for any location-specific time trends. The expenditure elasticity -0.426 (s.e. 0.128) is slightly larger under this specification, while the point estimates for prices and variety are barely affected by the inclusion of these additional fixed effects. In columns (4) to (6), we restrict our sample to large counties and obtain very similar results for all three dependent variables.

Symmetric Pass-Through

We test the symmetric pass-through assumption by comparing pass-through rates across classes of products within each module. Our approach consists in partitioning each module into several categories of UPCs and estimating short-run pass-through parameters separately for each of these categories. This is equivalent to testing for heterogeneous effects of sales tax changes on consumer prices across categories of products. Our first test was based on price levels, as described in the main text. Our second test of symmetric pass-through is based on a comparison of products or brands with different market shares. Results for theses specification checks are reported in Table A7.

In columns (1) through (4), pass-through rates are estimated separately for high- and low-market share UPCs, which are respectively defined as products with a time-invariant national market share above and below the module-specific median.[66] For both classes of products, the estimates are all consistent with full pass-through. Tests of equality of coefficients indicate that we reject the null under the specification with module-specific linear time trends, but that we fail to reject symmetric pass-through when module-time fixed effects are included (p-value=0.885).

In columns (5) through (10), we take a different approach. Formally, for each module, we aggregate UPCs into brands and compute the national market share for each brand. We then classify brands on the basis of their market shares in each module and define the top selling brand, the second selling brand and all remaining brands. Each UPC in the data is assigned to one of the categories based on that UPC's brand. Finally, for each module, we regress log price on UPC fixed effects and store-by-quarter fixed effects interacted with a categorical variable representing the brand popularity. This delivers a quarterly panel data set of store-module price indices with three price indices for each module-store-quarter cell. Differences between pass-through rates between top-selling brands and brands with relatively smaller market shares are reported in columns (5) through (7) for specifications with linear time trends, and correspondingly in columns (8) through (10) for models with module-time fixed effects. Again, all coefficients are suggestive of full-pass through, and differences across categories of products are economically small. The null hypothesis of equal pass-through rates is rejected in the first specification, but it is not in the model with module-specific time effects (p-value>0.1).

[66]Market shares are calculated using total sales between 2006 and 2014.

Table A1 : Examples of Universal Product Codes (UPC)

UPC Description	Module Description	Group Description	Department Description	Brand Description	Multi	Size	Units
M&M PLN DK CH HDY-M HDY	CANDY-CHOCOLATE-SPECIAL	CANDY	DRY GROCERY	M&M MARS M&M PLAIN	1	12.6	OZ
M&M PLN CH/TY SHREK 2 HL	CANDY-CHOCOLATE-SPECIAL	CANDY	DRY GROCERY	M&M MARS M&M PLAIN	1	1.75	OZ
M&M PLN CH DSP STAR WARS	CANDY-CHOCOLATE-SPECIAL	CANDY	DRY GROCERY	M&M MARS M&M PLAIN	1	1.06	OZ
R SSY E-C MSE AP CHFN	COSMETICS-EYE SHADOWS	COSMETICS	HEALTH & BEAUTY CARE	REVLON STAR STYLE	1	0.17	OZ
R SSY E-S PWD SQN	COSMETICS-EYE SHADOWS	COSMETICS	HEALTH & BEAUTY CARE	REVLON STAR STYLE	1	0.05	OZ
AXE AR R TWIST	DEODORANTS - COLOGNE TYPE	DEODORANT	HEALTH & BEAUTY CARE	AXE	1	4	OZ
CTL BR EGGS A LG	EGGS-FRESH	EGGS	DAIRY	CTL BR	1	12	CT
CTL BR B-E JMB	EGGS-FRESH	EGGS	DAIRY	CTL BR	1	12	CT
COKE CLS R CL NB 6P	SOFT DRINKS - CARBONATED	CARBONATED BEVERAGES	DRY GROCERY	COCA-COLA CLASSIC R	6	8	OZ
COKE CLS R CL CN &	SOFT DRINKS - CARBONATED	CARBONATED BEVERAGES	DRY GROCERY	COCA-COLA CLASSIC R	1	12	OZ
GPC 2 UL L M F UT 85 P - .30	CIGARETTES	TOBACCO & ACCESSORIES	NON-FOOD GROCERY	GPC	1	20	CT
GPC 2 UL L M F UT 85 C - 2.00	CIGARETTES	TOBACCO & ACCESSORIES	NON-FOOD GROCERY	GPC	10	20	CT

Source: Nielsen's Retail Scanner Data.

Table A2: Sales Tax Exemptions

Panel A: Food Modules

Module	Avg. Mkt. Share	States taxing all food	State taxing module at reduced rate	State taxing module at full rate (but otherwise exempt food)
DAIRY - MILK	3.04%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	
SOFT DRINKS - CARBONATED	2.88%	AL, ID, KS, MS, OK, SD	AR, IL, MO, TN,UT,VA	CA, CT, FL, IA, IN, KY, MD, ME, MN, NC, ND, NJ, NY, OH, PA, RI, TX, WA, WI, WV
BAKERY - BREAD - FRESH	2.19%	AL, ID, KS, MS, OK, SD	IL, MO, TN,UT,VA, WV	
CEREAL - READY TO EAT	1.93%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	
SOFT DRINKS - LOW CALORIE	1.62%	AL, ID, KS, MS, OK, SD	AR, IL, MO, TN,UT,VA	CA, CT, FL, IA, IN, KY, MD, ME, MN, NC, ND, NJ, NY, OH, PA, RI, TX, WA, WI, WV
WATER-BOTTLED	1.42%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	LA, MD, ME, MN, NY
ICE CREAM - BULK	1.22%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	FL, MD
COOKIES	1.21%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	
CANDY-CHOCOLATE	0.64%	AL, ID, KS, MS, OK, SD	AR, IL, MO, UT,VA,WV	CT, FL, IA, IN, KY, MD, ME, MN, NC, ND, NJ, NY, RI, TN, TX, WI

Notes: Average market shares are calculated at the store-level for the year 2008.

Table A2: Sales Tax Exemptions

Panel B: Non-Food Modules

Module	Avg. Mkt. Share	State with no sales tax	State exempting module	State taxing module at reduced rate
WINE - DOMESTIC	2.11%	DE, MT, NH, OR	PA, KS, KY, MA	
CIGARETTES	1.70%	DE, MT, NH, OR	CO, MN, OK	
TOILET TISSUE	1.07%	DE, MT, NH, OR	PA, NJ	
DETERGENTS - LIQUID	0.75%	DE, MT, NH, OR		
PAPER TOWELS	0.66%	DE, MT, NH, OR	NJ	
RUM	0.54%	DE, MT, NH, OR	PA, KS, KY, MA	
DISPOSABLE DIAPERS	0.50%	DE, MT, NH, OR	MA, MN, NJ, PA, VT	IL
MAGAZINES	0.41%	DE, MT, NH, OR	MA, ME, NY, OK	
CAT FOOD - DRY TYPE	0.35%	DE, MT, NH, OR		
COLD REMEDIES - ADULT	0.28%	DE, MT, NH, OR	CT, FL, MD, MN, NJ, NY, PA, TX, VA, VT	IL
DOG & CAT TREATS	0.25%	DE, MT, NH, OR		
ALE	0.25%	DE, MT, NH, OR	PA, KS, KY, MA	
DOG FOOD - WET TYPE	0.23%	DE, MT, NH, OR		
FACIAL TISSUE	0.22%	DE, MT, NH, OR	NJ	
TOOTH CLEANERS	0.22%	DE, MT, NH, OR	PA	IL

Notes: Average market shares are calculated at the store-level for the year 2008.

Table A2: Sales Tax Exemptions

Panel A: Food Modules

Module	Avg. Mkt. Share	States taxing all food	State taxing module at reduced rate	State taxing module at full rate (but otherwise exempt food)
DAIRY - MILK	3.04%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	
SOFT DRINKS - CARBONATED	2.88%	AL, ID, KS, MS, OK, SD	AR, IL, MO, TN,UT,VA	CA, CT, FL, IA, IN, KY, MD, ME, MN, NC, ND, NJ, NY, OH, PA, RI, TX, WA, WI, WV
BAKERY - BREAD - FRESH	2.19%	AL, ID, KS, MS, OK, SD	IL, MO, TN,UT,VA, WV	
CEREAL - READY TO EAT	1.93%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	
SOFT DRINKS - LOW CALORIE	1.62%	AL, ID, KS, MS, OK, SD	AR, IL, MO, TN,UT,VA	CA, CT, FL, IA, IN, KY, MD, ME, MN, NC, ND, NJ, NY, OH, PA, RI, TX, WA, WI, WV
WATER-BOTTLED	1.42%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	LA, MD, ME, MN, NY
ICE CREAM - BULK	1.22%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	FL, MD
COOKIES	1.21%	AL, ID, KS, MS, OK, SD	AR, IL, MO, NC, TN,UT,VA,WV	
CANDY-CHOCOLATE	0.64%	AL, ID, KS, MS, OK, SD	AR, IL, MO, UT,VA,WV	CT, FL, IA, IN, KY, MD, ME, MN, NC, ND, NJ, NY, RI, TN, TX, WI

Panel B: Non-Food Modules

Module	Avg. Mkt. Share	State with no sales tax	State exempting module	State taxing module at reduced rate
WINE - DOMESTIC	2.11%	DE, MT, NH, OR	PA, KS, KY, MA	
CIGARETTES	1.70%	DE, MT, NH, OR	CO, MN, OK	
TOILET TISSUE	1.07%	DE, MT, NH, OR	PA, NJ	
DETERGENTS - LIQUID	0.75%	DE, MT, NH, OR		
PAPER TOWELS	0.66%	DE, MT, NH, OR	NJ	
RUM	0.54%	DE, MT, NH, OR	PA, KS, KY, MA	
DISPOSABLE DIAPERS	0.50%	DE, MT, NH, OR	MA, MN, NJ, PA, VT	IL
MAGAZINES	0.41%	DE, MT, NH, OR	MA, ME, NY, OK	
CAT FOOD - DRY TYPE	0.35%	DE, MT, NH, OR		
COLD REMEDIES - ADULT	0.28%	DE, MT, NH, OR	CT, FL, MD, MN, NJ, NY, PA, TX, VA, VT	IL
DOG & CAT TREATS	0.25%	DE, MT, NH, OR		
ALE	0.25%	DE, MT, NH, OR	PA, KS, KY, MA	
DOG FOOD - WET TYPE	0.23%	DE, MT, NH, OR		
FACIAL TISSUE	0.22%	DE, MT, NH, OR	NJ	
TOOTH CLEANERS	0.22%	DE, MT, NH, OR	PA	IL

Notes: Average market shares are calculated at the store-level for the year 2008.

Table A3 : Descriptive Statistics

	All counties	Counties with high sales tax rate	Counties with low sales tax rate	Linear Relationship with tax rate
	Mean (s.d.)	Mean (s.d.)	Mean (s.d.)	Coefficient (s.e.)
	(1)	(2)	(3)	(4)
Retail Scanner Data				
Total grocery store sales in county ($ million)	74.5	85.9	62.7	0.061**
	(203.3)	(261.6)	(113.3)	(0.025)
Average store-level sales ($ million)	9.6	9.3	10.0	-0.051**
	(4.5)	(4.3)	(4.6)	(0.025)
Average store-level food share of total sales	0.753	0.751	0.754	0.086***
	(0.055)	(0.053)	(0.057)	(0.025)
Average store-module-level price index	-0.015	-0.015	-0.015	-0.149***
	(0.039)	(0.038)	(0.039)	(0.025)
Average store-module-level variety	101.3	99.0	103.7	-0.075***
	(23.7)	(23.3)	(23.9)	(0.025)
Number of grocery stores	6.5	7.6	5.4	0.071***
	(15.9)	(20.5)	(8.8)	(0.025)
Sales Taxes				
Average sales tax rate	0.063	0.073	0.052	
	(0.017)	(0.008)	(0.017)	
Average sales tax rate on food products	0.016	0.019	0.012	
	(0.022)	(0.025)	(0.019)	
Difference between effective rates on nonfood and food	0.047	0.054	0.040	
	(0.024)	(0.022)	(0.023)	
Other county characteristics				
Population	164,735	194,155	134,083	0.109***
	(415237)	(534496)	(229760)	(0.025)
Household median income	43,961	42,908	45,058	-0.041
	(11640)	(11504)	(11687)	(0.025)
Share population with high school degree or less	49.9	51.5	48.2	0.187***
	(11.2)	(11.1)	(11.1)	(0.025)
Land area	1,024	865	1,189	-0.170***
	(1565)	(1369)	(1731)	(0.025)
Other Taxes				
Property tax rate	0.009	0.009	0.009	-0.072***
	(0.005)	(0.005)	(0.005)	(0.025)
Average gasoline excise tax rate	0.264	0.264	0.263	-0.010
	(0.089)	(0.090)	(0.088)	(0.025)
Average cigarette excise tax ($)	1.287	1.269	1.316	0.031
	(0.893)	(0.983)	(0.816)	(0.025)
Average alcohol excise tax ($)	2.070	1.871	2.282	-0.349***
	(1.409)	(1.115)	(1.642)	(0.023)
Top Marginal Income Tax Rate	0.056	0.057	0.055	-0.073***
	(0.028)	(0.033)	(0.023)	(0.025)
Number of counties	1,560	796	764	1,560

Note: Sales tax rates efffective on September 1, 2008. Sales, pre-tax prices and variety are measured yearly, for 2008. The Retail Scanner data is restricted to modules above the 80th percentile of the national distribution of sales. Column 2 restricts the sample to counties for which the total sales tax rate is greater than the median, and column (3) is restricted to below-median counties. Column 4 reports the coefficient from a regression of the tax rate on the county characteristic. In each regressions, all variables are standardized with mean zero and unit variance.

* p<0.1 ** p<0.05 *** p<0.01

Table A4: The Long-Run Effect of Sales Taxes -- Difference-in-Differences Model

Dependent Variable:	Expenditure shares		Prices		Variety	
	(1)	(2)	(3)	(4)	(5)	(6)
Non-Food Module × $\log(1+\tau_{cs})$	-0.840	-0.810	0.893	0.845	-0.987	-1.092
	(0.574)	(0.414)	(0.074)	(0.049)	(0.299)	(0.200)
Specification:						
Store fixed effects	y	y	y	y	y	y
Module fixed effects	y		y		y	
Module × Region fixed effects		y		y		y
N (observations)	9,653,999	9,653,999	9,653,999	9,653,999	9,653,999	9,653,999
N (modules)	148	148	148	148	148	148
N (stores)	8,682	8,682	8,682	8,682	8,682	8,682
N (counties)	1,134	1,134	1,134	1,134	1,134	1,134
N (county-modules)	163,926	163,926	163,926	163,926	163,926	163,926
R^2	0.757	0.801	0.394	0.495	0.844	0.863

Notes: Sales tax rates efffective on September 1. Sales, prices and variety are measured yearly. The Retail Scanner data is restricted to modules above the 80th percentile of the national distribution of sales. The sample is restricted to states where food products are exempt from the state sales tax, and to modules that are either taxed or exempt in all of these states. All standard errors are clustered at the state-module level.

Table A5: Robustness of Long-Run Estimates to Alternative Specifications and Sample Restrictions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent Variable:									
Log of Expenditure Share	-0.683	-0.716	-1.032	-0.929	-1.115	-0.992	-0.824	-0.962	-0.744
	(0.255)	(0.198)	(0.294)	(0.255)	(0.251)	(0.207)	(0.347)	(0.265)	(0.112)
Log of Average Consumer Price	1.145	1.060	1.227	1.114	1.172	1.054	1.047	0.964	1.072
	(0.036)	(0.025)	(0.039)	(0.030)	(0.038)	(0.026)	(0.069)	(0.050)	(0.016)
Log of Variety (# of UPCs)	-0.848	-0.813	-0.801	-0.753	-0.916	-0.838	-0.737	-0.791	-0.909
	(0.148)	(0.123)	(0.192)	(0.169)	(0.146)	(0.122)	(0.215)	(0.166)	(0.068)
Specification:									
Store Fixed Effects	y	y	y	y	y	y	y	y	y
Module fixed effects	y		y		y		y		
Module × Region fixed effects		y		y		y		y	y
Restrict to Non-DD sample			y	y					
Restrict to Large Counties (>150k)					y	y			
Instrument with State Tax Rates							y	y	
Include Low Expenditure Modules									y
N (observations)	17,320,024	17,320,024	7,666,025	7,666,025	12,373,721	12,373,721	17,320,024	17,320,024	79,376,154
N (modules)	198	198	198	198	198	198	198	198	975
N (stores)	11,487	11,487	11,487	11,487	8,211	8,211	11,487	11,487	11,487
N (counties)	1,625	1,625	1,625	1,625	368	368	1,625	1,625	1,625
N (county-modules)	308,977	308,977	157,723	157,723	70,481	70,481	308,977	308,977	1,521,153

Notes: All coefficients are linear combinations of nine coefficients -- one for each year from 2006 to 2014. All standard errors are clustered at the state-module level. In columns (3) and (4), the sample is restricted to module-county cells that do not fullfil the restriction criteria of the difference-in-differences approach. Columns (5) and (6) restricts the sample to counties with a population larger than 150,000. The county-level effective tax rate is instrumented with the state-level effective rate in columns (7) and (8). In column (9), all modules that are sold in all 48 continental states are included.

Table A6: Robustness of Short-Run Estimates to Alternative Specifications and Sample Restrictions

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable:						
Log of Expenditure Share	-0.342	-0.165	-0.426	-0.389	-0.164	-0.536
	(0.111)	(0.103)	(0.128)	(0.119)	(0.109)	(0.134)
Log of Average Consumer Price	1.026	1.008	1.039	1.055	1.017	1.086
	(0.038)	(0.025)	(0.046)	(0.040)	(0.026)	(0.048)
Log of Variety (# of UPCs)	-0.025	-0.082	0.048	-0.067	-0.130	-0.019
	(0.079)	(0.071)	(0.105)	(0.087)	(0.077)	(0.113)
Specification:						
Store, Time, Module fixed effects	y	y	y	y	y	y
Module × Store fixed effects	y	y	y	y	y	y
Module-specific linear time trend	y		y	y		y
Module × Time fixed effects		y			y	
Store × Time fixed effects			y			y
Restrict to Large Counties (>150k)				y	y	y
Module × Pair-specific linear time trend						
N (observations)	68,076,928	68,076,928	68,076,928	48,680,109	48,680,109	48,680,109
N (modules)	198	198	198	198	198	198
N (stores)	11,487	11,487	11,487	8,211	8,211	8,211
N (counties)	1,625	1,625	1,625	368	368	368
N (quarters)	36	36	36	36	36	36
N (county-modules)	308,977	308,977	308,977	70,481	70,481	70,481

Notes: A unit of time is a quarter, and the period covered is 2006-2014. In columns (4) to (6), the sample is restricted to stores located in counties with a population greater than 150,000. Standard errors are clustered at the state-module level in all specifications.

Table A7: Symmetric Pass-Through - Robustness

Sample of UPCs:	High-market share	Low-market share	High-market share	Low-market share	Top-selling brand	2nd best-selling brand	All other brands	Top-selling brand	2nd best-selling brand	All other brands
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent Variable:										
Log of Average Consumer Price	1.048	0.970	1.018	1.014	1.125	1.030	0.964	1.073	1.001	0.992
	(0.040)	(0.038)	(0.027)	(0.026)	(0.052)	(0.052)	(0.039)	(0.040)	(0.039)	(0.027)
Symmetric pass-through (p-value)	0.009		0.885			0.002			0.118	
Specification:										
Store, Time, Module fixed effects	y		y			y			y	
Module × Store fixed effects	y		y			y			y	
Module-specific linear time trend	y					y				
Module × Time fixed effects			y						y	
N (observations)	135,401,768		135,401,768			192,934,542			192,934,542	
N (modules)	198		198			198			198	
N (stores)	11,487		11,487			11,487			11,487	
N (counties)	1,625		1,625			1625			1625	
N (quarters)	36		36			36			36	

Notes: A unit of time is a quarter, and the period covered is 2006-2014. All standard errors are clustered at the state-module level. All fixed effects are fully interacted with indicators for each UPC categories. The p-value reported is for a test of equality of coefficients.

Table A8: Model-based estimates of the variety effect

	Baseline	Robustness			
Long-run estimates	Pooled cross-section	Pooled cross-section (Table A5)	Pooled cross-section (Table A5)	Pooled cross-section	Pooled cross-section
Short-run estimates	Time series, full sample	Time series, full sample	Time series, full sample	Time series, full sample (Table A6)	Time series, full sample (Table A6)
	(1)	(2)	(3)	(4)	(5)
"Long-run" estimates (endogenous J, free entry)					
Pass-through rate, dlog(p)/dt	1.06	1.05	0.96	1.06	1.06
Quantity response, dlog(Q)/dt	-0.78	-1.05	-0.93	-0.78	-0.78
Variety response, dlog(J)/dt	-0.81	-0.92	-0.79	-0.81	-0.81
"Short-run" estimates (fixed J)					
Pass-through rate, dlog(p)/dt |J	1.03	1.03	1.03	1.04	1.06
Quantity response, dlog(Q)/dt |J	-0.37	-0.37	-0.37	-0.47	-0.44
Welfare estimates					
Variety Effect Parameter (scaled by J/(pQ) = 1/q)	1.360	2.035	2.048	0.831	0.966

Notes: This table reports calibration of the marginal welfare gain formulas in main text. In all columns, the results are based on assuming current tax rate is $0.063 per dollar. The first column reports the variety effects for our preferred estimates. In columns (2) and (3), we use long-run estimates from our robustness checks (Table A5, columns (6) and (8) respectively). In the last two columns, the short-run estimates from our robustness checks are used (Table A6, columns (3) and (4) respectively).

Table A9: Sources of sales tax exemption information

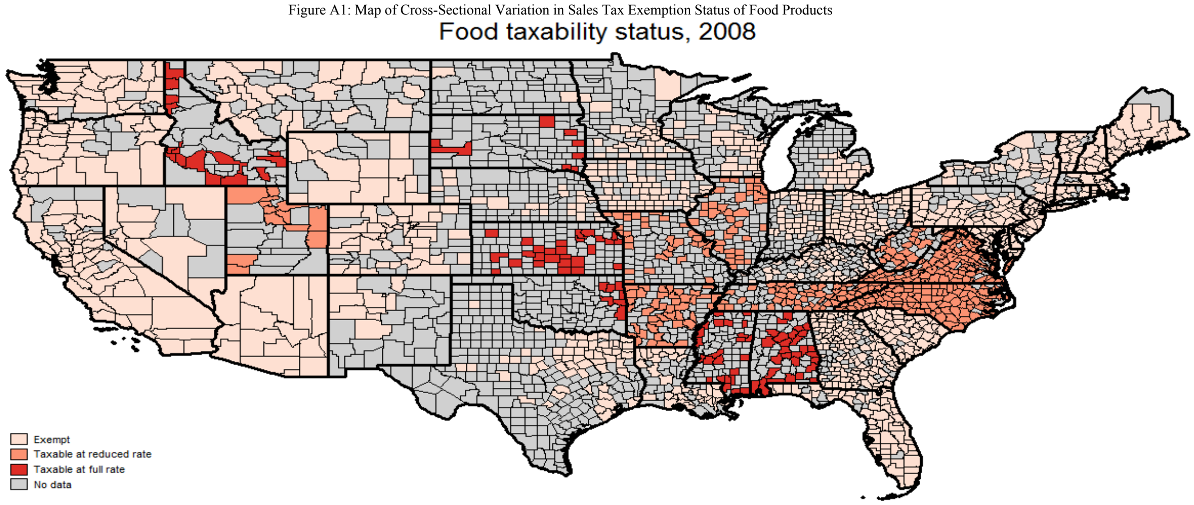
State	URLs	Type of Document
AL	http://revenue.alabama.gov/salestax/rules/810-6-5-.02.pdf	Laws and Regulations
AL	http://www.alabamaadministrativecode.state.al.us/docs/rev/810-6-3.pdf	Laws and Regulations
AL	http://revenue.alabama.gov/publications/business-taxes/sales/Sales_Tax--Sales_Tax_Brochure.pdf	Brochure
AZ	http://www.azleg.state.az.us/ArizonaRevisedStatutes.asp?Title=42	Laws and Regulations
AZ	http://www.azsos.gov/public_services/Title_15/15-05.htm	Laws and Regulations
AZ	https://www.azdor.gov/Portals/0/TPTRates/08012016RateTable.pdf	Table
AZ	https://www.azdor.gov/Portals/0/Brochure/575.pdf	Brochure
AR*	http://www.lexisnexis.com/hottopics/arcode/Default.asp	Laws and Regulations
AR*	http://www.dfa.arkansas.gov/offices/policyAndLegal/Documents/et2008_3.pdf	Laws and Regulations
AR*	http://www.dfa.arkansas.gov/offices/policyAndLegal/Documents/et2007_3.pdf	Laws and Regulations
AR*	http://www.dfa.arkansas.gov/offices/exciseTax/salesanduse/Documents/SalesTaxExemptionsFY2011.pdf	Brochure
CA	http://www.boe.ca.gov/lawguides/business/current/btlg/business-taxes-law-guide.html	Laws and Regulations
CA	https://www.boe.ca.gov/pdf/pub31.pdf	Brochure
CA	https://www.boe.ca.gov/pdf/pub27.pdf	Brochure
CA	https://www.boe.ca.gov/pdf/pub61.pdf	Brochure
CO	https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=4753	Laws and Regulations
CO	http://codes.findlaw.com/co/title-39-taxation/co-rev-st-sect-39-26-707.html	Laws and Regulations
CO	https://www.colorado.gov/pacific/sites/default/files/DR1002.pdf	Brochure
CO	https://www.colorado.gov/pacific/sites/default/files/Sales04.pdf	Brochure
CT	http://www.cga.ct.gov/2011/pub/chap219.htm	Laws and Regulations
CT	https://www.cga.ct.gov/2011/rpt/2011-R-0238.htm	Brochure
CT	http://www.ct.gov/drs/cwp/view.asp?A=1514&Q=563394	Brochure
CT	http://www.ct.gov/drs/cwp/view.asp?a=1511&q=267404	Brochure
DE	http://revenue.delaware.gov/services/current_bt/taxtips/grocery.pdf	Brochure
FL	http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&URL=0200-0299/0212/0212ContentsIndex.html	Laws and Regulations
FL	https://www.flrules.org/gateway/ChapterHome.asp?Chapter=12A-1	Laws and Regulations
FL	http://floridarevenue.com/Forms_library/current/dr46nt.pdf	Brochure
GA*	http://www.lexisnexis.com/hottopics/gacode/Default.asp	Laws and Regulations
GA*	http://garules.elaws.us/rule/560-12-2	Laws and Regulations
GA*	https://dor.georgia.gov/sites/dor.georgia.gov/files/related_files/document/LATP/Bulletin/2016%20List%20of%20Sales%20and%20Use%20Tax%20Exemptions.pdf	Brochure
ID	http://adminrules.idaho.gov/rules/current/35/0102.pdf	Laws and Regulations
ID	http://www.legislature.idaho.gov/idstat/Title63/T63CH36.htm	Laws and Regulations
ID	https://tax.idaho.gov/pubs/EBR00012_07-01-2001.pdf	Brochure
ID	https://tax.idaho.gov/pubs/EBR00016_03-23-2015.pdf	Brochure
IL	ftp://www.ilga.gov/JCAR/AdminCode/086/08600130sections.html	Laws and Regulations
IL	http://www.revenue.state.il.us/publications/Bulletins/2010/FY-2010-01.PDF	Brochure
IL	http://www.revenue.state.il.us/Publications/Pubs/Pub-117.pdf	Brochure
IN*	http://codes.findlaw.com/in/title-6-taxation/	Laws and Regulations
IN*	http://www.in.gov/legislative/iac/20080827-IR-045080658NRA.xml.pdf	Brochure
IA*	https://www.legis.iowa.gov/law/iowaCode/chapters?title=X	Laws and Regulations
IA*	http://law.justia.com/codes/iowa/2013/titlex/subtitle1/chapter423	Laws and Regulations
IA*	https://tax.iowa.gov/iowa-sales-tax-food	Brochure
KS*	http://kansasstatutes.lesterama.org/Chapter_79/	Laws and Regulations
KS*	http://rvpolicy.kdor.ks.gov/Pilots/Ntrntpil/IPILv1x0.NSF/$$ViewTemplate%20for%20Regulations%20Only?OpenForm	Laws and Regulations
KS*	http://www.ksrevenue.org/pdf/pub1510.pdf	Brochure
KY*	http://www.lrc.ky.gov/Statutes/chapter.aspx?id=37663	Laws and Regulations
KY*	http://www.lrc.ky.gov/kar/TITLE103.HTM	Laws and Regulations
KY*	http://revenue.ky.gov/Documents/AppendixN_CandyProduct91114.pdf	Brochure
KY*	http://revenue.ky.gov/News/Publications/Pages/Sales-Tax-Facts.aspx	Brochure
LA	http://www.legis.state.la.us/lss/lss.asp?folder=121	Laws and Regulations
LA	http://www.doa.louisiana.gov/osr/lac/61v01/61v01.doc	Laws and Regulations
LA	http://www.rev.state.la.us/Miscellaneous/FoodExemptionFlyer.pdf	Brochure
LA	http://revenue.louisiana.gov/Publications/R-1002(01-17)%20FINAL.pdf	Brochure

ME	http://www.mainelegislature.org/legis/statutes/36/title36ch0sec0.html	Laws and Regulations
ME	http://www.maine.gov/revenue/salesuse/Bull1220160101v2.pdf	Brochure
ME	http://www.maine.gov/revenue/salesuse/Bull2720160101v2.pdf	Brochure
MD	http://www.lexisnexis.com/hottopics/mdcode/	Laws and Regulations
MD	http://www.dsd.state.md.us/COMAR/title_search/Title_List.aspx	Laws and Regulations
MD	http://taxes.marylandtaxes.com/Resource_Library/Tax_Publications/Tax_Tips/Business_Tax_Tips/bustip5.pdf	Brochure
MA	https://malegislature.gov/Laws/GeneralLaws/PartI/TitleIX/Chapter64H	Laws and Regulations
MA	http://www.mass.gov/dor/individuals/taxpayer-help-and-resources/tax-guides/salesuse-tax-guide.html	Brochure
MI*	http://w3.lara.state.mi.us/orrsearch/948_2010-012TY_AdminCode.pdf	Laws and Regulations
MI*	https://www.michigan.gov/documents/treasury/RAB_2009-8_Food_for_Human_Consumption_Oct_09_299470_7.pdf	Brochure
MN*	https://www.revisor.mn.gov/statutes/?id=297A.67	Laws and Regulations
MN*	http://www.revenue.state.mn.us/businesses/sut/factsheets/FS102A.pdf	Brochure
MN*	http://www.revenue.state.mn.us/businesses/sut/factsheets/FS102B.pdf	Brochure
MN*	http://www.revenue.state.mn.us/businesses/sut/factsheets/FS102C.pdf	Brochure
MN*	http://www.revenue.state.mn.us/businesses/sut/factsheets/FS102D.pdf	Brochure
MN*	http://www.revenue.state.mn.us/businesses/sut/factsheets/FS117A.pdf	Brochure
MN*	http://www.revenue.state.mn.us/businesses/sut/factsheets/FS117F.pdf	Brochure
MS	http://www.lexisnexis.com/hottopics/mscode/	Laws and Regulations
MS	http://www.sos.ms.gov/admincodesearch/default.aspx	Laws and Regulations
MS	https://www.dor.ms.gov/Laws-Rules/Documents/Part%20IV%20Sales%20and%20Use%20Tax%2092216.pdf	Laws and Regulations
MS	http://www.dor.ms.gov/Business/Pages/Sales-Tax-Exemptions.aspx	Brochure
MO	http://www.moga.mo.gov/mostatutes/stathtml/14400000301.html	Laws and Regulations
MT	https://revenue.mt.gov/home/individuals/businesses_otherinformation#Sales%20Tax	Brochure
NE*	http://www.revenue.nebraska.gov/legal/regs/slstaxregs.html	Laws and Regulations
NE*	http://www.nebraskalegislature.gov/laws/browse-chapters.php?chapter=77	Laws and Regulations
NE*	http://www.revenue.nebraska.gov/info/6-432.pdf	Brochure
NE*	http://www.revenue.nebraska.gov/info/6-437.pdf	Brochure
NV*	http://www.leg.state.nv.us/NRS/NRS-372.html	Laws and Regulations
NV*	http://www.leg.state.nv.us/NAC/NAC-372.html	Laws and Regulations
NV*	https://tax.nv.gov/FAQs/Sales_Tax_Information___FAQ_s/	Brochure
NH	https://www.revenue.nh.gov/assistance/tax-overview.htm	Brochure
NJ*	http://law.justia.com/codes/new-jersey/2009/title-54/54-32b	Laws and Regulations
NJ*	http://www.state.nj.us/treasury/taxation/pdf/pubs/sales/su4.pdf	Brochure
NJ*	http://www.state.nj.us/treasury/taxation/pdf/ssutfood.pdf	Brochure
NM	http://www.nmcpr.state.nm.us/nmac/_title03/T03C002.htm	Laws and Regulations
NM	http://public.nmcompcomm.us/nmpublic/gateway.dll/?f=templates&fn=default.htm	Laws and Regulations
NM	http://realfile.tax.newmexico.gov/FYI-105%20-%20Gross%20Receipts%20&%20Compensating%20Taxes%20-%20An%20Overview.pdf	Brochure
NM	http://www.zillionforms.com/2016/P668403604.PDF	Brochure
NY	http://codes.findlaw.com/ny/tax-law/tax-sect-1105.html	Laws and Regulations
NY	https://govt.westlaw.com/nycrr/Document/I50f2201ecd1711dda432a117e6e0f345?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)	Laws and Regulations
NY	https://www.tax.ny.gov/pdf/publications/sales/pub840.pdf	Brochure
NY	https://www.tax.ny.gov/pdf/publications/sales/pub750.pdf	Brochure
NY	https://www.tax.ny.gov/pdf/memos/sales/m11_3s.pdf	Brochure
NY	https://www.tax.ny.gov/pdf/memos/sales/m06_6s.pdf	Brochure
NY	https://www.tax.ny.gov/pdf/tg_bulletins/sales/b11_525s.pdf	Brochure
NY	https://www.tax.ny.gov/pdf/tg_bulletins/sales/b14_103s.pdf	Brochure
NY	https://www.tax.ny.gov/pdf/tg_bulletins/sales/b11_160s.pdf	Brochure
NY	https://www.ny.gov/sites/ny.gov/files/atoms/files/GuideForTaxableandExemptPropertyandServices.pdf	Brochure
NC*	http://www.ncga.state.nc.us/gascripts/Statutes/StatutesTOC.pl?Chapter=0105	Laws and Regulations
NC*	http://www.dornc.com/practitioner/sales/bulletins/toc.html	Laws and Regulations
NC*	http://www.dornc.com/taxes/sales/foodnotice6-06.pdf	Brochure
ND*	http://law.justia.com/codes/north-dakota/2013/title-57/chapter-57-39.2	Laws and Regulations
ND*	https://www.nd.gov/tax/data/upfiles/media/gl-22062.pdf?20170414121353	Brochure
OH*	http://codes.ohio.gov/orc/5739	Laws and Regulations
OH*	http://www.tax.ohio.gov/portals/0/sales_and_use/information_releases/st200401.pdf	Brochure

OK*	http://law.justia.com/codes/oklahoma/2006/os68.html	Laws and Regulations
OK*	https://www.ok.gov/tax/documents/rule6509.pdf	Laws and Regulations
OK*	https://www.ou.edu/controller/fss/dwnload/SalesTax%20GeneralFAQs.pdf	Brochure
OR	http://landru.leg.state.or.us/ors/	Laws and Regulations
OR	http://arcweb.sos.state.or.us/pages/rules/oars_100/oar_150/150_tofc.html	Laws and Regulations
PA	http://www.pacode.com/secure/data/061/061toc.html	Laws and Regulations
PA	http://www.revenue.pa.gov/FormsandPublications/FormsforBusinesses/Documents/Sales-Use%20Tax/rev-717.pdf	Brochure
RI*	http://www.tax.ri.gov/regulations/FINAL%20REGS%202009/FoodandFoodIngredientsRegFinal%20v2%2002122010.pdf	Laws and Regulations
RI*	http://law.justia.com/codes/rhode-island/2010/title44/chapter44-18/	Laws and Regulations
RI*	http://www.tax.ri.gov/regulations/salestax/11-60.pdf	Laws and Regulations
RI*	http://www.tax.state.ri.us/streamlined/candy_soft_diet.php	Brochure
SC	http://www.scstatehouse.gov/code/t12c036.php	Laws and Regulations
SC	http://www.scstatehouse.gov/coderegs/c117.php	Laws and Regulations
SC	https://dor.sc.gov/resources-site/lawandpolicy/Advisory%20Opinions/RR06-5.pdf	Laws and Regulations
SC	https://dor.sc.gov/resources-site/publications/Publications/Sales%20and%20Use%20Tax%20Manual%202015%20Edition-Web.pdf	Brochure
SC	http://media.clemson.edu/procurement/2011SalesTaxSeminarManual_May.pdf	Brochure
SD*	http://legis.sd.gov/Statutes/Codified_Laws/DisplayStatute.aspx?Type=Statute&Statute=10-45	Laws and Regulations
SD*	http://dor.sd.gov/taxes/business_taxes/publications/pdfs/stguide2014.pdf	Brochure
SD*	http://dor.sd.gov/Publications/2013_Session_Presentations/PDFs/SummaryofStateSalesTaxExemptions0113.pdf	Brochure
TN*	http://www.lexisnexis.com/hottopics/tncode/	Laws and Regulations
TN*	https://www.tnumc.org/wp-content/uploads/2016/04/TN-Sales-Tax-booklet-2013.pdf	Brochure
TN*	https://revenue.support.tn.gov/hc/en-us/article_attachments/202401125/Notice__13-05.pdf	Brochure
TX	http://www.statutes.legis.state.tx.us/	Laws and Regulations
TX	https://comptroller.texas.gov/taxes/publications/96-280.pdf	Brochure
TX	https://comptroller.texas.gov/taxes/publications/94-155.pdf	Brochure
TX	https://comptroller.texas.gov/taxes/audit/docs/convenience-manual.pdf	Brochure
UT*	http://le.utah.gov/UtahCode/chapter.jsp?code=59	Laws and Regulations
UT*	http://www.tax.utah.gov/sales/food-rate	Brochure
UT*	http://www.tax.utah.gov/forms/pubs/pub-25.pdf	Brochure
VT*	http://www.leg.state.vt.us/statutes/sections.cfm?Title=32&Chapter=233	Laws and Regulations
VT*	http://www.state.vt.us/tax/pdf.word.excel/legal/regs/SU.finals.11012010.pdf	Laws and Regulations
VT*	http://tax.vermont.gov/sites/tax/files/documents/SalesTaxTaxable%26ExemptFS.pdf	Brochure
VA	http://law.lis.virginia.gov/vacode/title58.1/chapter6/	Laws and Regulations
VA	http://lis.virginia.gov/000/reg/TOC23010.HTM#C0210	Laws and Regulations
VA	https://www.tax.virginia.gov/laws-rules-decisions/rulings-tax-commissioner/05-78	Brochure
VA	https://www.tax.virginia.gov/sites/default/files/inline-files/TB%2013-5%20Nonprescription%20Drugs.pdf	Brochure
WA*	http://apps.leg.wa.gov/rcw/default.aspx?cite=82.08	Laws and Regulations
WA*	http://apps.leg.wa.gov/WAC/default.aspx?cite=458-20	Laws and Regulations
WA*	http://dor.wa.gov/Docs/Pubs/SpecialNotices/2012/sn_12_SoftDrinks.pdf	Brochure
WA*	http://dor.wa.gov/Docs/Pubs/SpecialNotices/2010/sn_10_WaterCandyGumTaxRepeal.pdf	Brochure
WA*	http://dor.wa.gov/content/aboutus/statisticsandreports/stats_ExemptionStudy.aspx	Brochure
WV*	http://www.legis.state.wv.us/wvcode/Code.cfm?chap=11&art=1	Laws and Regulations
WV*	http://tax.wv.gov/Documents/TSD/tsd300.pdf	Brochure
WV*	http://tax.wv.gov/Documents/TSD/tsd419.pdf	Brochure
WV*	http://tax.wv.gov/Documents/TSD/tsd420.pdf	Brochure
WI*	https://docs.legis.wisconsin.gov/statutes/statutes/77/III/51	Laws and Regulations
WI*	https://www.revenue.wi.gov/DOR%20Publications/pb220.pdf	Brochure
WY*	http://www.lexisnexis.com/hottopics/wystatutes/	Laws and Regulations
WY*	http://revenue.wyo.gov/home/rules-and-regulations-by-chapter	Laws and Regulations
WY*	http://revenue.wyo.gov/FoodExemption.pdf?attredirects=0	Brochure

* States indexed participate in the Streamlined Sales Tax Project (SSTP): http://www.streamlinedsalestax.org/

Figure A1: Map of Cross-Sectional Variation in Sales Tax Exemption Status of Food Products



Note: 'No data' indicates counties for which no grocery store sales were recorded in Nielsen's Retail Scanner data in 2008.