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ABSTRACT

This paper studies commodity taxation in a model featuring heterogeneous consumers, imperfect competition, and tax salience. We derive new formulas for the incidence and marginal excess burden of commodity taxation, and we find that tax salience and market structure interact when considering tax incidence but do not directly interact when considering the marginal excess burden. We estimate the necessary inputs to the formulas by combining Nielsen Retail Scanner data from grocery stores in the US with detailed sales tax data. We calibrate our new formulas and conclude that the incidence of sales taxes on consumers is increasing in tax salience, and the marginal excess burden of taxation is larger than standard formulas that ignore imperfect competition and tax salience.

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1 Introduction

Standard welfare analysis of commodity taxation typically makes two key assumptions: (1) the product market is perfectly competitive and (2) consumers respond to taxes in the same way they respond to price changes. Several papers in public economics have relaxed the first assumption (see Auerbach and Hines 2002 for a review of this literature), but these papers have maintained the second assumption that taxes are fully salient. More recently, researchers have relaxed the second assumption, developing new theoretical and empirical tools to analyze the welfare effects of taxes when taxes are less salient than prices, but have maintained the assumption of perfect competition (Chetty, Looney, and Kroft 2009; Taubinsky and Rees-Jones 2018; Farhi and Gabaix 2020; Morrison and Taubinsky 2020). If markets are characterized by imperfect competition and consumers misperceive taxes, however, neither of these approaches is likely to provide a fully accurate characterization of the welfare effects of commodity taxes.

This paper contributes to the behavioral public finance literature in several ways. First, we derive new formulas for the incidence and marginal excess burden of commodity taxes (both unit taxes and ad valorem taxes) in a model featuring imperfect competition and tax salience with heterogeneous consumers. These formulas lead to the key novel insights of this paper. Tax salience and market structure *interact* when considering tax incidence, but do not directly interact when considering the marginal excess burden.

For incidence, we show that greater attention to taxes can increase the incidence on consumers under imperfect competition in contrast to the standard model of perfect competition which predicts the opposite pattern. Thus, the standard intuition of how tax salience affects the incidence of taxation in perfectly competitive markets does not always carry over to imperfect competition. We also derive new results about how heterogeneity in consumer inattention to taxes affects incidence both under perfect competition and imperfect competition.[1] We show that consumer heterogeneity affects pass-through and incidence under all market structures including perfect competition.[2] Of

[1]While Taubinsky and Rees-Jones (2018) study how consumer heterogeneity affects the efficiency cost of taxation under perfect competition, they do not consider incidence.

[2]With imperfect competition, there is an additional effect of heterogeneity on pass-through. Intuitively, when the

particular relevance for firms with market power is how inattention correlates with the price elasticity of demand. We show that firms bear less of the burden of taxes when elastic consumers are more inattentive to taxes. Thus, the covariance between consumer inattention and price elasticity is important for incidence analysis.

Turning to welfare, we find that tax salience and market structure do not directly interact when considering the efficiency cost of taxation, which means that tax salience affects the welfare cost of taxation in similar ways under perfect and imperfect competition. We also find, similar to Taubinsky and Rees-Jones (2018) and Farhi and Gabaix (2020), that heterogeneous inattention to taxes induces misallocation, and we generalize these results by showing that this misallocation does not directly interact with market structure. Specifically, we find that greater dispersion in inattention increases the welfare cost of taxes in similar ways under perfect and imperfect competition.[3]

Second, we provide new estimates of the necessary inputs to our tax formulas using Nielsen Retail Scanner data covering grocery stores selling consumer goods in the U.S. combined with county-level and state-level sales tax data. We estimate the effect of taxes on consumer prices and quantity demanded using a regression model that leverages variation in sales taxes within states and counties over time, and another regression model that focuses on differences between "border pair" counties located on opposite sides of a state border (Holmes 1998; Dube, Lester and Reich 2010). We also estimate the price elasticity of demand based on an instrumental variable strategy which exploits the "uniform pricing" across stores within retail chains (DellaVigna and Gentzkow 2019). Our estimates indicate nearly-complete pass-through of taxes onto consumer prices, and a tax elasticity of demand that is smaller in magnitude than the price elasticity of demand. We combine these estimates to provide a new estimate of tax salience, which is fairly similar to other estimates reported in the literature.

Lastly, we calibrate our new tax formulas using these empirical estimates. A novel feature of

consumer response to taxes is heterogeneous, this effectively changes the slope of the inverse demand curve facing the firm and the firm takes this into account when choosing prices.

[3]Of course, market structure and salience do interact indirectly through the sufficient statistics that determine the efficiency cost of taxation; for example, tax salience affects the equilibrium price which affects the markup and hence the excess burden under imperfect competition.

our approach is the use of the pass-through formula and the generalized Lerner index to calibrate the average markup, which enters in the marginal excess burden formula. Our calibration results show that accounting for imperfect competition and tax salience meaningfully changes the incidence and marginal excess burden of sales taxes. We find a lower incidence of taxes on consumers (as compared to perfect competition), and we find that increased attention to taxes leads to consumers bearing a *larger* share of the burden of the tax. We examine the sensitivity to consumer heterogeneity and find that accounting for heterogeneity in consumers' inattention to taxes further lowers the incidence of taxes on consumers. Turning to welfare, Chetty, Looney and Kroft (2009) show that when consumers underreact to sales taxes, the standard formula (Harberger 1964) exaggerates the true marginal excess burden of sales taxes. However, our new formula shows that this may no longer be the case under imperfect competition, since there is a pre-existing distortion coming from firms' market power. In fact, our calibration results suggest that even though consumers underreact to taxes, the Harberger formula nevertheless *understates* – rather than overstates – the marginal excess burden of sales taxes. Intuitively, this is because the markup scales one-for-one in the welfare formula, while the mean and variance of the tax salience parameter scales with the tax rate, as in the case of perfect competition. Overall, we interpret these results as revealing the importance of jointly accounting for tax salience and imperfect competition when analyzing the incidence and efficiency costs of commodity taxation, and our general formulas show how to incorporate these features in a unified framework.

Our paper is related to several streams of research. First, our paper builds on and contributes to the literature on taxation and imperfect competition (see, e.g., Seade 1987; Stern 1987; Delipalla and Keen 1992; Anderson, de Palma, and Kreider 2001a; Anderson, de Palma and Kreider 2001b; Auerbach and Hines 2001; Weyl and Fabinger 2013; Hackner and Herzing 2016; Adachi and Fabinger 2019; Miravete, Seim, and Thurk 2018). Our paper innovates in several ways. First, we consider a general model of imperfect competition and do not impose a functional form for preferences or technology, similar to Weyl and Fabinger (2013).[4] Second, we permit consumers to

[4]Weyl and Fabinger (2013) only consider tax incidence. They do not consider the efficiency costs of taxation.

underreact to taxes and allow for heterogeneity in the degree of underreaction. Third, we derive our new formulas for both ad valorem and unit taxes (allowing for tax salience) and compare these formulas, which is important since existing theoretical work finds that these taxes are not equivalent under imperfect competition (Delipalla and Keen 1992). Lastly, unlike most of the research in this area, we provide an empirical application that allows us to calibrate our new formulas, which contributes to the literature studying sales taxes empirically (see, e.g., Besley and Rosen 1999; Einav et al. 2014; Baker, Johnson, and Kueng 2018).

We also contribute to the literaure in behavioral public economics (Liebman and Zeckhauser 2004; Chetty, Looney and Kroft 2009; Bordalo, Gennaioli, and Shleifer 2013; Goldin and Hominoff 2013; Kőszegi and Szeidl 2013; Allcott and Taubinsky 2015; Caplin and Dean 2015; Taubinsky and Rees-Jones 2018; Allcott, Lockwood, and Taubinsky 2018; Bradley and Feldman 2019; Farhi and Gabaix 202; Morrison and Taubsinky 2020). Most of the papers in this literature assume perfect competition. Bradley and Feldman (2019), which examines tax incidence in a monopoly setting with inattentive consumers, is an important exception. Relative to this paper, we allow for heterogeneity in tax salience across consumers, allow for more general forms of imperfect competition, and move beyond incidence to also study the efficiency cost of taxation. The joint consideration of incidence and efficiency analysis is important for our calibration approach, which combines both tax formulas to identify the markup which appears in the marginal excess burden formula.

The remainder of the paper is organized as follows: Section 2 begins with a model of perfect competition and considers the welfare effects of a unit tax. Section 3 extends the results to monopoly and the general model of imperfect competition. Section 4 derives analagous formulas for the case of an ad valorem tax and compares the incidence and efficiency costs of ad valorem and unit taxes. Section 5 discusses the data and the empirical results. Section 6 presents the calibration results. Section 7 concludes.

2 Perfect Competition

We are interested in characterizing the incidence and marginal excess burden effects of commodity taxation allowing for salience effects. Following Weyl and Fabinger (2013), we define the incidence of a unit tax t as $I{=}\frac{dCS/dt}{dPS/dt}$ and the marginal excess burden of the tax as $\frac{dW}{dt} = \frac{dCS}{dt}{+}\frac{dPS}{dt}{+}\frac{dR}{dt}$ where CS denotes consumer surplus, PS denotes producer surplus, R denotes government revenue, and $W = CS{+}PS{+}R$ denotes social welfare.[5]

Let p denote the producer price and $p + t$ denote the price paid by consumers. We assume that there is a mass 1 of consumers and we index each consumer by i. Consumer i has exogenous income Z_i and quasilinear utility given by $U_i(q, y) = u_i(q) + y$, where q is consumption of the taxed good and y is the numeraire good. We follow Chetty, Looney and Kroft (2009) by assuming that 1) taxes affect utility only through their effects on the chosen consumption bundle and that 2) in the absence of taxation, consumers perfectly optimize so that $p = u_i'(q)$ when $t = 0$. We define willingness to pay for consumer i as $wtp_i(q) \equiv u_i'(q)$ and marginal willingness to pay for consumer i as $mwtp_i(q) \equiv u_i''(q)$.

Let $D_i(p, t)$ be the observed demand of individual i. Our specification for observed demand permits prices and taxes to have different effects, following Chetty, Looney and Kroft (2009). Assume that for $t > 0$, $D_i(p, 0) > D_i(p, t) > D_i(p + t, 0)$. By strict monotonicity and continuity, for all p and t there exists a $\theta_i(p, t) \in (0, t)$ such that $D_i(p + \theta_i(p, t), 0) = D_i(p, t)$. For fixed t and all i, we assume that if $D_i(p + \theta_i, 0) = D_i(p, t)$ for some price p, then $D_i(p' + \theta_i, 0) = D_i(p', t)$ for any other price p'. This implies that $\theta_i(p, t) = \theta_i(t)$ does not depend on the producer price p. We further assume that $\theta_i(t)$ is linear and write it as $\theta_i(t) = \theta_i t$ which is without loss of generality on the shape of the original inverse demand curve $u_i'(q) = wtp_i(q)$. This definition satisfies $\theta_i = \frac{\frac{\partial D_i}{\partial t}}{\frac{\partial D_i}{\partial p}}$ which is how this parameter is defined in Chetty, Looney and Kroft (2009), but we allow for consumer heterogeneity following Taubinsky and Rees-Jones (2018) and Farhi and Gabaix (2020). Total quantity demanded is given by $D(p, t) = \int D_i(p, t) di$. We assume that $D(p, t)$ is strictly

[5] It is well known that unit taxes and ad valorem taxes are equivalent under perfect competition. Section 4 considers the case of an ad valorem tax under imperfect competition.

decreasing in both arguments and continuous. Let $\epsilon_D \equiv -\frac{\partial D(p,t)}{\partial p}\frac{p+t}{D}$ denote the price elasticity of demand evaluated at the consumer price.

We define production similar to Chetty, Looney and Kroft (2009) and Taubinsky and Rees-Jones (2018). In particular, firms are price takers and use $c(S)$ units of the numeraire good to produce S units of output. The marginal cost of production is $c'(S)$ and we assume that firms perfectly optimize so that firm supply is given by $p = c'(S(p))$ where $S(p)$ is strictly increasing and continuous in p. Define $\epsilon_S \equiv \frac{\partial S}{\partial p}\frac{p}{S}$ as the price elasticity of supply.

The equilibrium price, p, in the market for the taxed good is determined by the condition $D(p,t) = S(p)$. Let $\epsilon_{Dt} \equiv \frac{dq(t)}{dt}\frac{p+t}{q(t)}$ be the elasticity of equilibrium output, $q(t) \equiv D(p(t),t)$, with respect to the tax t. Note that ϵ_{Dt} need not equal $\frac{\partial D}{\partial t}\frac{p+t}{q(t)}$; the latter holds the pre-tax price, p, fixed, while the former includes any indirect effect of taxes on the producer price. We denote the pass-through rate by $\rho \equiv 1 + dp/dt$.

We begin by introducing a technical assumption which helps to simplify the analysis throughout and connect our formulas to ones that exist in the literature.

Assumption 1. *The demand function $D_i(p,t)$ can be represented by the linear approximation $\hat{D}_i(p,t) = q_{i0} + \frac{\partial D(p_0,t_0)}{\partial p}(p - p_0 + \theta_i(t - t_0))$ around $(q_{i0}, p_0, t_0, \theta_i)$ for $q_{i0} = D_i(p_0,t_0)$ for each individual i.*[6]

Assumption 1 is a formal statement of the approximation given in Bernheim and Taubinsky (2018) that allows us to focus on heterogeneity in salience effects across consumers, holding the price responses across consumers constant. The expression in Assumption 1 is a first-order approximation rather than an exact expression because even assuming price responses are the same across consumers at all quantity levels is not sufficient for Assumption 1 to hold exactly unless demand curves are linear. We next introduce a lemma which turns out to be quite useful in deriving all of the incidence formulas that we present in the paper.

Lemma 1. *The following relationship holds between the demand elasticities, pass-through and*

[6]In case this assumption is violated, the model given by $\hat{D}_i(p,t)$ is a linear approximation to the real model with a common slope for all i. The corollaries that follow below apply to this linear approximation.

inattention to taxes:

$$\epsilon_{Dt} = -(\mathbb{E}(\theta_i) + \rho - 1)\epsilon_D + \frac{p+t}{q(t)} Cov\left(\theta_i, \frac{\partial D_i(p,t)}{\partial p}\right)$$

Under Assumption 1, we obtain the following relationship:

$$\epsilon_{Dt} = -(\mathbb{E}(\theta_i) + \rho - 1)\epsilon_D$$

Proof. See Appendix. □

Given the definitions and Lemma 1, we can derive the following proposition and corollary for the incidence and efficiency costs of taxation. The corollary uses Assumption 1 to provide expressions that ignore heterogeneity in price responses across consumers. We note that while the results on efficiency already exist for perfect competition when consumers are heterogeneous (see Taubinsky and Rees-Jones 2018), the results in this section on incidence are novel. For example, Chetty, Looney and Kroft (2009) consider incidence under the assumptions of identical consumers and no pre-existing taxes.

Proposition 1. *Define* $q_i(t) \equiv D_i(p(t), t)$ *and* $q(t) \equiv D(p(t), t)$*. The incidence on consumers, producers, government, the pass-through rate and the marginal excess burden of a unit tax,* t*, under* ***perfect competition*** *may be expressed as:*

$$\begin{aligned}
\frac{dCS}{dt} =& -\rho q - (1-\mathbb{E}(\theta_i))t\frac{dq}{dt} + tCov\left(\theta_i, \frac{dq_i}{dt}\right) \\
\frac{dPS}{dt} =& -(1-\rho)q \\
\frac{dR}{dt} =& q + t\frac{dq}{dt} \\
\rho =& 1 - (1-\omega)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right), \text{ where } \omega \equiv \frac{1}{1 + \frac{\epsilon_D}{\epsilon_S}\frac{p}{p+t}} \\
I =& \frac{\rho}{1-\rho} + \frac{1-\mathbb{E}(\theta_i)}{1-\rho}\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{q(1-\rho)}Cov\left(\theta_i, \frac{dq_i}{dt}\right) \\
\frac{dW}{dt} =& t\mathbb{E}(\theta_i)\frac{dq}{dt} + tCov\left(\theta_i, \frac{dq_i}{dt}\right)
\end{aligned}$$

Proof. See Appendix. □

Corollary 1. *Under Assumption 1, the effect of the tax on consumer surplus, producer surplus, pass-through, incidence and welfare can be expressed as:*

$$\frac{dCS}{dt} = -\rho q - (1 - \mathbb{E}(\theta_i))t\frac{dq}{dt} + tVar(\theta_i)\frac{\partial D}{\partial p}$$
$$\frac{dPS}{dt} = -(1-\rho)q$$
$$\rho = 1 - (1-\omega)\,\mathbb{E}(\theta_i), \text{ where } \omega \equiv \frac{1}{1 + \frac{\epsilon_D}{\epsilon_S}\frac{p}{p+t}}$$

$$I = \frac{\rho}{1-\rho} + \frac{1}{1-\rho}\frac{t}{p+t}\left((1-\mathbb{E}(\theta_i))\,\epsilon_{Dt} - Var(\theta_i)\,\epsilon_D\right)$$
$$\frac{dW}{dt} = t\mathbb{E}(\theta_i)\frac{dq}{dt} + tVar(\theta_i)\frac{\partial D}{\partial p}$$

We highlight several features of Proposition 1 and Corollary 1. First, when $t = 0$, the formulas for the effects of a tax on consumer surplus and producer surplus, and hence incidence, are identical to Weyl and Fabinger (2013), except that the pass-through term, ρ, is indirectly affected by salience effects.[7] Intuitively, on the consumer side, when there are no taxes in the baseline equilibrium, consumers optimize and so the envelope theorem applies. Salience only affects consumers and producers at the market level through changes in prices, as in Chetty, Looney, and Kroft (2009). In particular, since $\omega < 1$ with perfect competition, an increase in $\mathbb{E}(\theta_i)$ leads to a lower pass-through and incidence on consumers. We also see that, in the presence of heterogeneous consumers, pass-through depends on the new term $Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)$. Intuitively, what matters for incidence is the initial shift in demand in response to taxes and the price elasticities of demand and supply which determine how much prices need to adjust to re-equilibrate the market. Since individual-level responses to taxes can be written as $\frac{\partial D_i}{\partial t} = \theta_i \frac{\partial D_i}{\partial p}$, the market-level response to taxes depends on the covariance between θ_i and $\frac{\partial D_i}{\partial p}$ across i.

Second, when $t > 0$, the effect of a change in the tax on consumer surplus depends on two additional terms, $-(1-\mathbb{E}(\theta_i))t\frac{dq}{dt}$ and $tCov\left(\theta_i, \frac{dq_i}{dt}\right)$.[8] In this case, one has to account for behavioral

[7] It is analytically convenient to express the pass-through formula this way where ω is the pass-through rate when consumers fully optimize with respect to taxes, as it will facilitate a comparison between the different cases (perfect competition, monopoly, and imperfect competition).

[8] Chetty, Looney and Kroft (2009) fully characterized the effects of a tax on consumer surplus in terms of the pass-

responses to the tax since the envelope theorem does not apply when consumers misoptimize in the baseline equilibrium. The first term, $-(1-\mathbb{E}(\theta_i))t\frac{dq}{dt}$, resembles the "self-control adjustment" term in equation (10) in Gruber and Kőszegi (2004). It enters $\frac{dCS}{dt}$ positively whenever $\frac{dq}{dt} < 0$ and we see that more inattention to taxes reduces the incidence on consumers, conditional on the pass-through rate and the behavioral response to the tax. Intuitively, if consumers are overspending on taxable goods at baseline (because $\mathbb{E}(\theta_i) < 1$), then a tax increase that causes them to reduce their demand brings them closer to their optimal choice. The second term, $tCov\left(\theta_i, \frac{dq_i}{dt}\right)$, represents a misallocation term. When Assumption 1 holds, Corollary 1 shows that this term collapses to $tVar\left(\theta_i\right)\frac{\partial D}{\partial p}$ which mirrors the expression in Taubinsky and Rees-Jones (2018) and Bernheim and Taubinsky (2018). If consumers are fully attentive to the tax so that $\theta_i = 1$ for all i, we see that $\frac{dCS}{dt}$ and I are characterized purely by the price effect, even with a pre-existing tax.

Third, independent of the baseline tax or the degree of inattention to the tax, when supply is perfectly elastic ($\epsilon_S = \infty$), $\rho = 1$ and the full burden of the tax is on consumers so that $I = \infty$.

Lastly, the marginal excess burden of the tax is scaled by the degree of inattention to the tax, $\mathbb{E}(\theta_i)$, and includes an additional term reflecting the dispersion in inattention, as in Taubinsky and Rees-Jones (2018). In the case where $\theta_i = 0$ for all i, taxes are not distortionary since with quasilinear utility, the consumption allocation is the same as the consumption allocation with a lump-sum tax, as shown in Chetty, Looney, and Kroft (2009).

3 Imperfect Competition

3.1 Monopoly

In this section, we depart from the benchmark case of perfect competition and consider a model of imperfect competition. In order to develop intuition, we begin with the special case of monopoly. We assume that the monopolist's cost of production is given by $c(q)$, with marginal cost $mc(q) \equiv$

through rate, ρ. Our results show that pass-through is not sufficient for incidence when there are both salience effects and pre-existing taxes in the market.

$c'(q)$, and we define $\epsilon_S \equiv \frac{c'(q)}{c''(q)q}$. When consumers are identical, the monopoly problem is particularly simple since in this case, $\theta(p,t) = \theta t$ and $D(p+\theta t, 0) = D(p,t)$ and we may express the inverse demand function facing the firm as $P(q,t) = wtp(q) - \theta t$, where $wtp(q)$ is the inverse of $D(\cdot, 0)$. The monopolist's problem in this case can be stated as:

$$\max_q \left(wtp(q) - \theta t\right) q - c(q)$$

The first-order condition for the monopoly problem is $wtp'(q)q + wtp(q) - \theta t = mc(q)$. In this case, $mr(q) = wtp'(q)q + wtp(q)$ is shifted down by θt. If the tax was fully non-salient so that $\theta = 0$, then consumer demand is not affected by taxes.

In the general case with consumer heterogeneity, we follow the setup from last section where for each i, $D_i(p+\theta_i t, 0) = D_i(p,t)$, and $D(p,t) \equiv \int D_i(p,t)di$. As before, the market demand elasticity is defined as $\epsilon_D \equiv -\frac{\partial D(p,t)}{\partial p}\frac{p+t}{D}$. We now introduce several new definitions which are relevant for characterizing incidence and efficiency under imperfect competition. First, we define the representative agent's willingness to pay $wtp(q)$ as the inverse of $D(\cdot, 0)$.[9] Next, define the marginal willingness to pay as $mwtp(q) \equiv wtp'(q)$. Then $ms(q) \equiv -mwtp(q)q$ is marginal consumer surplus and the elasticity of marginal surplus is given by $\epsilon_{ms} \equiv \frac{ms(q)}{ms'(q)q}$. Furthermore, define $MS(q,t) = -\frac{q}{\frac{\partial D}{\partial p}(p(t),t)} = \frac{ms(q)}{mwtp(q(t)) * \frac{\partial D}{\partial p}(p(t),t)}$. Note that $MS(q,0) = ms(q)$, and define $MS_t \equiv \frac{\partial MS}{\partial t}$. Given these definitions, we can now characterize the incidence and marginal excess burden of taxes for monopoly.

Proposition 2. *The incidence on consumers, producers, government, the pass-through rate and the*

[9] Formally, there is no representative agent for the economy since even with quasilinear utility there is a problem of aggregation given the misoptimization with respect to taxes. However, when $t = 0$ the economy admits a representative agent (given that there are no income effects) and we use the inverse demand function of this representative agent to characterize average and marginal consumer surplus.

marginal excess burden of a unit tax, t, under ***monopoly*** *may be expressed as:*

$$\frac{dCS}{dt} = -\rho q - (1-\mathbb{E}(\theta_i))t\frac{dq}{dt} + tCov\left(\theta_i, \frac{dq_i}{dt}\right)$$

$$\frac{dPS}{dt} = -q\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right)$$

$$\frac{dR}{dt} = q + t\frac{dq}{dt}$$

$$\rho = 1-(1-\omega)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right) + \omega MS_t, \textit{ where } \omega = \frac{1}{1+\frac{\epsilon_D\frac{p}{p+t}-1}{\epsilon_S}+\frac{1}{\epsilon_{ms}}}$$

$$I = \frac{\epsilon_D}{\frac{p+t}{q}\mathbb{E}\left(\theta_i\frac{\partial D_i}{\partial p}\right)}\left(\rho + (1-\mathbb{E}(\theta_i))\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{q}Cov\left(\theta_i, \frac{dq_i}{dt}\right)\right)$$

$$\frac{dW}{dt} = (p - mc(q) + \mathbb{E}(\theta_i)t)\frac{dq}{dt} + tCov\left(\theta_i, \frac{dq_i}{dt}\right)$$

Proof. See Appendix. □

Corollary 2. *Under Assumption 1, the effect of the tax on consumer surplus, producer surplus, pass-through, incidence and welfare can be expressed as:*

$$\frac{dCS}{dt} = -\rho q - (1-\mathbb{E}(\theta_i))t\frac{dq}{dt} + tVar(\theta_i)\frac{\partial D}{\partial p}$$

$$\frac{dPS}{dt} = -q\mathbb{E}(\theta_i)$$

$$\rho = 1-(1-\omega)\mathbb{E}(\theta_i), \textit{ where } \omega = \frac{1}{1+\frac{\epsilon_D\frac{p}{p+t}-1}{\epsilon_S}+\frac{1}{\epsilon_{ms}}}$$

$$I = \frac{1}{\mathbb{E}(\theta_i)}\left(\rho + (1-\mathbb{E}(\theta_i))\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{p}Var(\theta_i)\epsilon_D\right)$$

$$\frac{dW}{dt} = (p - mc(q) + \mathbb{E}(\theta_i)t)\frac{dq}{dt} + tVar(\theta_i)\frac{\partial D}{\partial p}$$

Several interesting insights emerge from the analysis of salience and taxation under monopoly. First, we note that the formula characterizing the effects of the tax on consumer surplus is identical to the formula in the case of perfect competition. Note, however, that the *inputs* to the formula are different under monopoly as we discuss below.

Next, we see that the effects of a tax on producer surplus is $-q\left(\mathbb{E}(\theta_i)+\frac{Cov\left(\theta_i,\frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right)$. Consider first the case where $\theta_i = 1$ for all i. Since the monopolist sets the price (and level of output), the effect of a small change in taxes is simply the mechanical effect of the tax change which is given by output, q. Consumer inattention attenuates the effect of taxes on producers since instead of consumer demand falling by the amount of the tax change, it falls by this amount scaled by the degree of inattention $\mathbb{E}(\theta_i)$. The covariance term $Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)$ incorporates the correlation between θ_i and $\frac{\partial D_i}{\partial p}$ which determines the market-level demand response to the tax. When $Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right) > 0$, the incidence on the monopolist is attenuated.[10] This can be easily seen in the binary case where there are two types of consumers: those who optimize and those who are fully inattentive to taxes. If those who optimize are price inelastic and those who are inattentive are price elastic, then the monopolist earns higher profit compared to the case where inattention is uncorrelated with price elasticity. In fact, it may be optimal for the monopolist to fully disclose taxes (e.g., post tax-inclusive prices) if there are enough consumers who are both highly price elastic and overreact to taxes (so that $\theta_i > 1$).[11] This result on optimal disclosure of taxes relates to Veiga and Weyl (2016) on how firms can optimally use nonprice product features to sort profitable from unprofitable consumers. Finally, we note that the formula holds even when $mc(q)$ is constant so that $\epsilon_S = \infty$. This contrasts with perfect competition where $\frac{dPS}{dt} = 0$ when $\epsilon_S = \infty$.

Third, there are interesting effects of salience on pass-through, ρ, which operate through the elasticity of marginal surplus, which is positive (negative) if demand is log convex (log concave). In particular, unlike the case of perfect competition, the monopoly outcome may be associated with $\omega > 1$ which implies that an increase in $\mathbb{E}(\theta_i)$ raises incidence on consumers. To see this, con-

[10]Since $\frac{\partial D_i}{\partial p} < 0$, this requires that consumers that are attentive to taxes are price inelastic; in other words, the absolute value of $\frac{\partial D_i}{\partial p}$ is negatively correlated with θ_i. Note that DellaVigna and Gentzkow (2019) find that high-income stores face less price elastic consumers and Taubinsky and Rees-Jones (2018) find that θ_i is higher for higher income individuals. This evidence suggests that $Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right) > 0$.

[11]Morrison and Taubinsky (2020) find that some consumers overreact to taxes but do not investigate whether this is correlated with their price elasticity of demand. To see why disclosure is never optimal when $\theta_i < 1$ for all consumers, consider the case where the monopolist discloses taxes at some q^*. If the monopolist then shrouds taxes, it could still sell q^* but at a higher price since the inverse demand curve with hidden taxes lies *everywhere* above the inverse demand curve with salient taxes. Thus, there is a profitable deviation and so disclosure can never be optimal when all consumers are inattentive to taxes.

sider the case of constant marginal cost and suppose demand has constant pass-through form so that $\epsilon_{ms} = -\epsilon$ (Bulow and Pfleiderer 1983) and $\theta_i = \theta$. Under these assumptions, $\rho = 1 - \frac{\theta}{1-\epsilon}$ so that $\frac{d\rho}{d\theta} = \frac{1}{\epsilon - 1}$, and so if demand is sufficiently elastic, then $\frac{d\rho}{d\theta} > 0$ and increased attention to the tax makes consumers *worse off,* in contrast to the logic in Chetty, Looney and Kroft (2009) under perfect competition.[12] We also see that the expression for ρ in the case of monopoly depends additionally on MS_t. Up to first order this term can be approximated by $MS_t \approx \frac{-q}{\left(\frac{\partial D}{\partial p}\right)^2} Cov\left(\frac{\partial^2 D_i}{\partial p^2}, \theta_i\right)$ (see Appendix). This new term captures that when taxes change and consumers vary in their degree of inattention, this effectively changes the slope of the demand curve. Since the optimal price depends on the slope of the demand curve, the monopolist exploits this change in market power when re-optimizing prices. If more attentive consumers become more price elastic when taxes change, then $Cov\left(\frac{\partial^2 D_i}{\partial p^2}, \theta_i\right) < 0$ and $MS_t > 0$. Intuitively, when the tax increases there is a reallocation of demand, whereby the negative output response q_i is bigger (in absolute value) for more attentive and price elastic consumers; in the case where $Cov\left(\frac{\partial^2 D_i}{\partial p^2}, \theta_i\right) < 0$, the average (or market) demand becomes more inelastic as demand is reallocated to more inelastic and less attentive consumers. Therefore, pass-through increases ($MS_t > 0$). Corollary 2 shows that this term vanishes under Assumption 1.

Finally, the effects of salience on the marginal excess burden of the tax operate in similar ways under perfect competition and monopoly through the terms $\mathbb{E}(\theta_i)t$ and $tCov\left(\theta_i, \frac{dq_i}{dt}\right)$; however, under monopoly the marginal excess burden depends additionally on the markup, $p - mc(q)$. We note that changes in markup will have larger effects on excess burden than changes in $\mathbb{E}(\theta_i)$ since the latter are scaled by the tax rate t. In the simple case where $mc(q)$ is constant, a smaller value of $\mathbb{E}(\theta_i)$ leads to a higher equilibrium price and so all else equal, this will additionally affect the marginal excess burden.

To summarize, the analysis of the incidence and welfare consequences of a tax for the special case of monopoly suggests that the standard intuition for the case of perfect competition does not always apply when firms have market power. Instead, there are interesting interactions between tax

[12] Note that even when $\epsilon_S = \infty$, the full incidence is not on consumers, unlike the case of perfect competition, although we note that this result holds independent of salience effects.

salience and market structure. This motivates our analysis of tax salience in a more general model of imperfect competition.

3.2 Symmetric Imperfect Competition

We consider a differentiated product market (the "inside market") which is subject to a unit tax t on each product in the market. Following Auerbach and Hines (2001) and Weyl and Fabinger (2013), we assume that markets for other goods are perfectly competitive and are not subject to taxation. There is a mass 1 of consumers each indexed by i with exogenous income Z_i. For each i, preferences are given by the quasilinear utility function $u_i(q_1, \ldots, q_J)+y$, where q_j is the quantity consumed of product $j = 1, \ldots, J$ and $y \in \mathbb{R}$ is the numeraire (representing consumption in all the outside markets). We assume that the subutility function, u_i, which represents preferences for the differentiated products, is strictly quasi-concave, twice differentiable, and symmetric in all of its arguments. The pre-tax (or producer) price for product j is given by p_j and the after-tax (or consumer) price is given by $p_j + t$ for all $j = 1, ..., J$. We define $u_i(Q_i) \equiv u_i(Q_i/J, \ldots, Q_i/J)$ to be the compact notation of utility for the symmetric case where the individual consumes $q_i = \frac{Q_i}{J}$ units of each product $j = 1, \ldots, J$, where Q_i is the aggregate quantity consumed by the individual.

Following Chetty, Looney and Kroft (2009), consumer i demand for product j is given by $q_j^i = q_j^i(p_1, \ldots, p_J, t)$ which is a function of both pre-tax prices and the tax. In order to connect our tax formulas to empirical objects, it is necessary to relate observed demand $q_j^i(p_1, \ldots, p_J, t)$ to consumer willingness to pay. We thus make the following assumptions which mirror assumptions $A1$ and $A2$ in Chetty, Looney and Kroft (2009).

Assumption 2. *Taxes affect utility only through their effects on the chosen consumption bundle. Indirect utility is given by:*

$$V^i(p_1, \ldots, p_J, t, Z_i) = u_i(q_1^i(p_1, \ldots, p_J, t), \ldots, q_J^i(p_1, \ldots, p_J, t))+Z_i-(p_1+t)q_1^i-\cdots-(p_J+t)q_J^i$$

Assumption 2 requires that taxes or salience have no impact on utility beyond their effects on consumption.

Assumption 3. *When tax-inclusive prices are fully salient, the agent chooses the same allocation as a fully-optimizing agent.*

$$(q_1^i, \ldots, q_J^i)(p_1 + t, \ldots, p_J + t, 0) = \arg \max_{(q_1, \ldots, q_J)} u_i(q_1, \ldots, q_J) + Z_i - (p_1 + t)q_1 - \cdots - (p_J + t)q_J$$

Assumption 3 implies that when tax-inclusive prices are fully salient, agents maximize utility. As in Section 2 we allow for salience effects by considering the possibility that $q_j^i(p_1, ..., p_J, 0) > q_j^i(p_1, ..., p_J, t) > q_j^i(p_1 + t, ..., p_J + t, 0)$.

In what follows, we assume that the demand function $q_j^i(\cdot)$ is symmetric in all other prices which we denote by $(p_k)_{-j}$ and twice differentiable and denote by $q_i(p, t)$ demand corresponding to symmetric prices and J firms: $q_i(p, t) \equiv q_j^i(p, ..., p, t)$. Without loss of generality on the functional form of $q_i(\cdot, 0) = \frac{(u_i')^{-1}(\cdot)}{J}$, we assume $q_i(p, t) = q_i(p + \theta_i t, 0)$ for some $\theta_i > 0$; therefore, the salience parameter satisfies $\theta_i = \frac{\frac{\partial q_j^i}{\partial t}}{\frac{\partial q_j^i}{\partial p}}$ and is the same for all products j for individual i.

We define individual i's market demand as $Q_i(p, t) = Jq_i(p, t)$. Total market demand is then given by $Q(p, t) = \int Q_i(p, t)di$, from where we define the market demand elasticity $\epsilon_D \equiv -\frac{\partial Q(p,t)}{\partial p} \frac{p+t}{Q}$. Also, for an economy without taxes, we define the representative agent's willingness to pay $wtp(Q)$ as the inverse of $Q(\cdot, 0)$, and let $mwtp(Q) = wtp'(Q)$ be the marginal willingness to pay. Then $ms(Q) = -mwtp(Q)Q$ is the marginal consumer surplus and the elasticity of marginal surplus is given by $\epsilon_{ms} \equiv \frac{ms(Q)}{ms'(Q)Q}$. Furthermore, define $MS(Q, t) = -\frac{Q}{\frac{\partial Q}{\partial p}(p(t), t)} = \frac{ms(Q)}{mwtp(Q(t)) * \frac{\partial Q}{\partial p}(p(t), t)}$, then $MS(Q, 0) = ms(Q)$, and let $MS_t \equiv \partial MS$.

Let $q_j(p_1, ..., p_J, t) = \int q_j^i(p_1, ..., p_J, t)di$. On the supply side, we allow for different forms of competition by introducing the market conduct parameter $\nu_p = \frac{\partial p_k}{\partial p_j}$ $(k \neq j)$ following Weyl and Fabinger (2013). Assume each firm produces a single product and has cost function $c_j(q_j) = c(q_j)$, where $c(\cdot)$ is increasing and twice differentiable with $c(0) = 0$ and $mc(q_j) \equiv c'(q_j)$. Firm j chooses p_j to maximize profits π_j:

$$\max_{p_j} \pi_j = p_j q_j(p_1 \ldots, p_J, t) - c(q_j(p_1 \ldots, p_J, t))$$

$$\text{s.t. } \frac{\partial p_k}{\partial p_j} = \nu_p \text{ for } k \neq j$$

The first-order condition for p_j is given by:

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

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

$$q_j(p_j,p,\ldots,p,t)+(p_j-mc(q_j))\left(\frac{\partial q_j(p_j,p,\ldots,p,t)}{\partial p_j}+(J-1)\nu_p\frac{\partial q_j(p_j,p,\ldots,p,t)}{\partial p_k}\right)=0, k\neq j$$

We assume that $\frac{\partial \pi_j}{\partial p_j}(p_j,p)$ is strict single crossing (from above) in p_j and decreasing in p so that a unique symmetric equilibrium $p(t)$ exists.[13] By letting $\nu_q = \frac{1}{mwtp(Q)} \times \frac{1}{\frac{dq_j}{dp_j}} = \frac{1}{mwtp(Q)} \times \frac{1}{\frac{\partial q_j}{\partial p_j}+\nu_p\sum_{k\neq j}\frac{\partial q_j}{\partial p_k}}$ we can rewrite the first-order condition as a generalized Lerner index:

$$\frac{p-mc(q)}{p+t}=\frac{\nu_q}{J\epsilon_D} \tag{1}$$

Setting $\nu_q = J$ yields the monopoly (perfect collusion) outcome and setting $\nu_q = 0$ gives the perfect competition (marginal cost pricing) solution. Setting $\nu_q = 1$ corresponds to Cournot competition when goods are homogeneous and setting $\nu_p = 0$ yields the Bertrand-Nash equilibrium. The model thus captures a wide range of market conduct.

We assume that tax revenue $R = tQ$ and profits $J\pi$ are redistributed to the consumers as a lump-sum transfer. The consumer treats profits and tax revenue as fixed when choosing consumption, failing to consider the external effects on the lump-sum transfer. Given the assumption of quasilinear utility, the consumer will choose to allocate the lump-sum transfer to the outside market y. Thus, total welfare, W, is given by the sum of consumer surplus (CS), producer surplus (PS) and government revenue (R).

$$W(p,t)=\underbrace{\int u_i(Q_i(p,t))di-(p+t)Q(p,t)}_{CS}+\underbrace{pQ-Jc\,(q)}_{PS}+\underbrace{tQ}_{R}$$

We can now state our main result. Consider a small increase in the tax t which applies to all goods in the inside market.

Proposition 3. *The incidence on consumers, producers, government, the pass-through rate and the*

[13]The case of strategic complementarities, where $\frac{\partial \pi_j}{\partial p_j}(p_j,p)$ is increasing in p allows for the existence of multiple symmetric equilibria. However, in that case if we assume there is a continuous and symmetric equilibrium selection $p(t)$ the same results follow.

marginal excess burden of a unit tax, t, under ***symmetric imperfect competition*** *may be expressed as:*

$$\frac{dCS}{dt} = -\rho Q - (1-\mathbb{E}(\theta_i))t\frac{dQ(p(t),t)}{dt} + tCov\left(\theta_i, \frac{dQ_i(p(t),t)}{dt}\right)$$

$$\frac{dPS}{dt} = -\left(1-\frac{\nu_q}{J}\right)[Q(1-\rho)] - \frac{\nu_q}{J}\left[Q\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right)\right]$$

$$\frac{dR}{dt} = Q + t\frac{dQ(p(t),t)}{dt}$$

$$\rho = 1-(1-\omega)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right) + \omega\frac{\nu_q}{J}MS_t \text{ where } \omega = \frac{1}{1+\frac{\epsilon_D\frac{p}{p+t}-\frac{\nu_q}{J}}{\epsilon_S}+\frac{\frac{\nu_q}{J}}{\epsilon_{ms}}}$$

$$I = \frac{\rho + (1-\mathbb{E}(\theta_i))\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{Q}Cov\left(\theta_i, \frac{dQ_i(p(t),t)}{dt}\right)}{(1-\rho)\left(1-\frac{\nu_q}{J}\right) + \frac{\nu_q}{J}\frac{\mathbb{E}\left(\theta_i\frac{\partial Q_i}{\partial p}\right)}{\mathbb{E}\left(\frac{\partial Q_i}{\partial p}\right)}}$$

$$\frac{dW}{dt} = (p-mc(q)+\mathbb{E}(\theta_i)t)\frac{dQ(p(t),t)}{dt} + tCov\left(\theta_i, \frac{dQ_i(p(t),t)}{dt}\right)$$

Proof. See Appendix. □

Corollary 3. *Under Assumption 1, the effect of the tax on consumer surplus, producer surplus, pass-through, incidence and welfare can be expressed as:*

$$\frac{dCS}{dt} = -\rho Q - (1-\mathbb{E}(\theta_i))t\frac{dQ(p(t),t)}{dt} + tVar(\theta_i)\frac{\partial Q}{\partial p}$$

$$\frac{dPS}{dt} = -Q\left[\left(1-\frac{\nu_q}{J}\right)(1-\rho) + \frac{\nu_q}{J}\mathbb{E}(\theta_i)\right]$$

$$\rho = 1-(1-\omega)\mathbb{E}(\theta_i), \text{ where } \omega = \frac{1}{1+\frac{\epsilon_D\frac{p}{p+t}-\frac{\nu_q}{J}}{\epsilon_S}+\frac{\frac{\nu_q}{J}}{\epsilon_{ms}}}$$

$$I = \frac{\rho + (1-\mathbb{E}(\theta_i))\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{p+t}Var(\theta_i)\epsilon_D}{(1-\rho)\left(1-\frac{\nu_q}{J}\right) + \frac{\nu_q}{J}\mathbb{E}(\theta_i)}$$

$$\frac{dW}{dt} = (p-mc(q)+\mathbb{E}(\theta_i)t)\frac{dQ(p(t),t)}{dt} + tVar(\theta_i)\frac{\partial Q}{\partial p}$$

Proposition 3 leads to several additional insights. First, $\frac{dCS}{dt}$ has the same expression as perfect competition and monopoly. Thus, the change in consumer surplus does not depend directly on market conduct, except insofar as market conduct determines pass-through. Second $\frac{dPS}{dt}$ is a convex combination of the monopoly and perfect competition cases with weights $\frac{\nu_q}{J}$ and $1-\frac{\nu_q}{J}$, respectively. To understand this expression, note that when $\theta_i = 1$ for all i, $\frac{dPS}{dt} = -Q\left((1-\rho)+\rho\frac{\nu_q}{J}\right)$, similar to Weyl and Fabinger (2013). When firms have market power, they internalize the change in their own output on the market (given by $\frac{\nu_q}{J}$), and so we need to adjust the price effect by $\rho\frac{\nu_q}{J}$. Under monopoly, this effect becomes ρ and $\frac{dPS}{dt} = -Q$. Similar to monopoly, if firms have market power, then salience directly attenuates the reduction in demand due to taxes and thus reduces the tax burden on producers.

We again see that in the general case, there are interesting effects of salience on pass-through depending on the magnitudes of ν_q and ϵ_{ms}. As in the monopoly case, greater attention to taxes can increase the burden on consumers if there is overshifting of taxes, again illustrating that salience and the degree of competition *interact* in determining the relative incidence of taxes on consumers and producers. In the simpler case of Corollary 3, the only role that salience plays is attenuating the initial response of consumer demand to a change in taxes. The intuition for this result is that, conditional on the demand response to taxes, salience does not directly affect the equilibrium response of prices. Conditional on this response, the firm's equilibrium response to the tax is determined purely by standard forces such as the marginal cost function, the shape of the demand curve and market conduct. Mathematically, this is because ω depends on supply and demand fundamentals and the conduct parameter. Salience only affects the weighting on ω in the expression for ρ. Thus, conditional on ω, the role of salience in affecting pass-through will be similar whether firms have a lot of market power (as in Monopoly) or only a little bit of market power (as in Bertrand or Cournot). However, in Proposition 3 we see that the expression for ρ depends additionally on $\omega\frac{\nu_q}{J}MS_t$. Like in monopoly, this term can be approximated by $MS_t \approx \frac{-Q}{\left(\frac{\partial Q}{\partial p}\right)^2}Cov\left(\frac{\partial^2 Q_i}{\partial p^2}, \theta_i\right)$ (see Appendix), but now it is weighted by $\frac{\nu_q}{J}$ — the relative distance of firm behavior to the monopoly benchmark. In the previous section we explain how this term captures that when taxes change, because consumers vary in their degree of inattention, there is a reallocation effect that effectively changes the elasticity of the demand curve.

Finally, we see that the marginal excess burden formula depends on the same set of sufficient statistics as in the monopoly case. In particular, the conduct parameter does not appear in the formula, and thus the intuition for welfare in the monopoly case carries over to the general model. Intuitively, the marginal excess burden of taxes is the lost social surplus that accrues from discouraging transactions in which the value of the product exceeds the cost of production. The marginal value of product with quasilinear utility is simply $p + \mathbb{E}(\theta_i)t$. The marginal cost of production is $mc(q)$. The discouraged transactions is represented by $dQ(p(t),t)/dt$ and we have the misallocation term which depends on $Var(\theta_i)$. Note that price effects do not show up in the formula since they are transfers between consumers and firms. Of course, the inputs to the formula, such as p and $mc(q)$, will depend on market conduct, but conditional on them, conduct does not independently affect the marginal excess burden.

4 Ad Valorem versus Unit Taxes

It is well known that ad valorem and unit taxes are not equivalent in imperfectly competitive markets (Delipalla and Keen 1992, Anderson, de Palma and Kreider 2001a, Adachi and Fabinger 2019). This section extends our results on incidence and excess burden in Proposition 3 to ad valorem taxes in the presence of salience effects. We consider the model of imperfect competition with both unit taxes and ad valorem taxes. The purpose of the model is to compare the incidence and welfare effects of these taxes and to forge a link with the empirical section which considers ad valorem taxes. For ease of exposition, we assume identical consumers and present the general expressions for ad valorem taxes in the presence of heterogeneous consumers that we calibrate in Section 6.

Let p denote the producer price and let $p(1+\tau)+t$ denote the price paid by consumers where τ is the ad valorem tax and t is the unit tax. Demand is given by $D(p,t,\tau)$ and assume that for $\tau > 0$ and $t > 0$, $D(p,0,0) > D(p,t,\tau) > D(p(1+\tau)+t,0,0)$. For any triple (p,t,τ) there exists $\theta_\tau(p,t,\tau)$ and $\theta_t(p,t,\tau)$ to be such that: $D(p,t,\tau) = D(p(1+\theta_\tau \tau)+\theta_t t,0,0)$. However following the literature and to simplify the setup assume θ_τ and θ_t are independent of the level of prices and tax rates. Equivalently we could define $\theta_\tau \equiv \frac{\frac{\partial D}{\partial \tau}}{\frac{\partial D}{\partial p}} \times \frac{1}{p}$ and $\theta_t \equiv \frac{\frac{\partial D}{\partial t}}{\frac{\partial D}{\partial p}}$ and assume they are constant with respect to prices and taxes.[14] Following the prior section, we extend the definition of willingness to pay to accommodate the ad valorem tax so that $wtp(Q) = p(1+\theta_\tau \tau) + \theta_t t$.

Let $\epsilon_D \equiv -\frac{\partial Q}{\partial p}\frac{p(1+\tau)+t}{Q}$, $\epsilon_D^* = \epsilon_D \frac{p}{p(1+\tau)+t}$ and define the pass-through rates for ad valorem and unit taxes respectively, as $\rho_\tau \equiv \frac{1}{p}\frac{\partial(p(1+\tau)+t)}{\partial \tau}$ and $\rho_t \equiv \frac{\partial(p(1+\tau)+t)}{\partial t}$. The following lemma shows how to identify θ_τ with commonly observable objects.

Lemma 2. *Let $\epsilon_{D\tau} \equiv \frac{dQ}{d\tau}\frac{p(1+\tau)+t}{Q}$. The following relationship holds:*

$$\epsilon_{D\tau} = -\epsilon_D * \frac{p}{1+\tau}\left(\left(1+\theta_\tau \tau\right)\rho_\tau + \theta_\tau - 1\right)$$

and

$$\theta_\tau = \frac{\left(1-\rho_\tau\right)p\epsilon_D - \epsilon_{D\tau}(1+\tau)}{\left(1+\tau\rho_\tau\right)p\epsilon_D}$$

Proof. See Appendix. □

With Lemma 2 in hand, we can now state our main proposition for ad valorem taxes. Following the literature, we compare the pass-through rates and the marginal cost of public funds. We begin with the characterization of pass-through rates.

Proposition 4. *In the symmetric model of imperfect competition, the pass-through rates for ad valorem and unit taxes are given respectively as:*

$$\rho_\tau = 1 - \frac{(1+\tau)\theta_\tau}{1+\theta_\tau \tau}\left(1 - \omega\frac{mc(q)}{p}\right)$$

$$\rho_t = 1 - \frac{(1+\tau)\theta_t}{1+\theta_\tau \tau}\left(1-\omega\right)$$

where $\omega = \frac{1}{1+\frac{(1+\theta_\tau \tau)\epsilon_D^* - \frac{\nu_q}{J}}{\epsilon_S} + \frac{\nu_q}{J}\frac{1}{\epsilon_{ms}}}$.

This implies that the two pass-through rates can be ranked based on the following:

$$\frac{\rho_\tau - 1}{\rho_t - 1} = \frac{\theta_\tau}{\theta_t}\frac{\omega\frac{mc}{p} - 1}{\omega - 1} = \frac{\theta_\tau}{\theta_t}\left(1 - \frac{\omega}{\omega-1}\frac{\nu_q}{J\epsilon_D^*}\right)$$

Proof. See Appendix. □

[14]Note that in the denominator of θ_τ and θ_t, the derivative is with respect to the first argument of D.

A first observation is that when $\theta_\tau = \theta_t$, if $mc < p$ then $\rho_\tau < \rho_t$ which is consistent with the literature (Delipalla and Keen 1992; Adachi and Fabinger 2019). Thus, if consumers underreact to ad valorem and unit taxes similarly, the pass-through rate is lower for ad valorem taxes. A new observation is that even under perfect competition starting from $p = mc$, ad valorem taxes imply a higher pass-through than unit taxes $\rho_t < \rho_\tau$ if and only if the consumers are more responsive to ad valorem taxes than unit taxes $\theta_\tau > \theta_t$. Most of the available empirical evidence in the literature applies to sales taxes and thus, θ_τ. Our results stress the need for additional evidence on θ_t.

Next, we derive the marginal cost of public funds for an ad valorem tax and a unit tax which are defined as $MC_\tau \equiv -\frac{dW/d\tau}{dR/d\tau}$ and $MC_t \equiv -\frac{dW/dt}{dR/dt}$, respectively.

Proposition 5. *Denote $wtp = p(1+\theta_\tau\tau) + \theta_t t$ the perceived price by the consumer and $\epsilon_D^* = \epsilon_D \frac{p}{p(1+\tau)+t}$. The marginal cost of public funds for an ad valorem tax, τ, and a unit tax, t, under **symmetric imperfect competition** may be expressed as:*

$$MC_\tau = \epsilon_D^* \frac{\frac{wtp-mc}{p}}{\frac{1+\tau\rho_\tau}{(1+\theta_\tau\tau)\rho_\tau+\theta_\tau-1} - \epsilon_D^*(\tau+\frac{t}{p})}$$

$$MC_t = \epsilon_D^* \frac{\frac{wtp-mc}{p}}{\frac{1+\tau\rho_t}{(1+\theta_\tau\tau)\rho_t+\theta_t-1} - \epsilon_D^*(\tau+\frac{t}{p})}$$

This implies the following:

$$\frac{MC_t}{MC_\tau} = \frac{\frac{1+\tau\rho_\tau}{(1+\theta_\tau\tau)\rho_\tau+\theta_\tau-1} - \epsilon_D^*(\tau+\frac{t}{p})}{\frac{1+\tau\rho_t}{(1+\theta_\tau\tau)\rho_t+\theta_t-1} - \epsilon_D^*(\tau+\frac{t}{p})}$$

In other words, the cost of ad-valorem taxes is lower than the cost of unit taxes ($MC_\tau < MC_t$) if and only if

$$\theta_\tau \left[1 - \frac{1+\tau(1+\theta_\tau-\theta_t)}{1+\theta_\tau\tau}\left(1-\omega\frac{mc}{p}\right)\right] < \theta_t \left[1 - \frac{1+\tau}{1+\theta_\tau\tau}(1-\omega)\right]$$

Proof. See Appendix. □

It is instructive to consider the benchmark case where $\theta_\tau = \theta_t$. In this case, $MC_\tau < MC_t$ if and only if $p > mc$. Thus, as long as consumers respond symmetrically to ad valorem and unit taxes, then salience does not affect the well-known result that ad valorem taxes are more efficient than unit taxes under imperfect competition. Of course, if consumers are sufficiently more attentive to ad valorem taxes than unit taxes, then this result shows that ad valorem taxes can be more distortionary than unit tax.

5 Data and Estimation

5.1 Data Description

Nielsen Retail Scanner Data We measure prices and quantity using the Nielsen Retail Scanner (RMS) data from $2006-2014$. This data set records sales and the number of units sold per week for roughly 2.5 million products which are designated as Universal Product Codes (UPC) for 35,000 stores in the United States (excluding Hawaii and Alaska) that are part of roughly 90 retail chains.

The UPCs are organized by Nielsen according to a hierarchical structure.[15] At the lowest rung are approximately 1,200 *product-module*s (e.g., fresh eggs, chocolate candy, olive oil, bleach, toilet tissue). Each module is assigned to one of roughly 120 *product-groups* (e.g. candy, shortening and oil, laundry supplies, paper products). These groups belong to one of 10 broader *product-departments* (e.g., dry grocery, fresh produce, non-food grocery). Stores are assigned to one of five possible store types: grocery, drug, mass merchandise, convenience, and liquor stores. Each store has a "parent company" that corresponds to the company that owns the store, and the data also indicates when multiple stores are part of the same retail chain.

We limit our sample to grocery stores for two reasons. First, the distribution of store types varies considerably across counties. By focusing on one store type, we ensure that compositional differences across counties are not driving our results. Second, we use an instrumental variables strategy which relies on uniform pricing within retail chains following DellaVigna and Gentzkow (2019). There are too few retail chains for non-grocery stores, making this strategy infeasible these store types. We follow DellaVigna and Gentzkow in further restricting our sample to (1) stores that belong to the same retail chain throughout $2006-2014$, (2) stores that are present in the data for at

[15] Appendix Table OA.1 describes the hierarchy of the data using example UPCs. UPCs without a barcode such as random weight meat, fruits, and vegetables are excluded from our sample.

least two years, and (3) stores that belong to retail chains that were associated with the same parent company throughout the sample period. In terms of products, we keep all products in modules that are sold in all 48 continental states and we restrict the sample to top-selling modules that rank above the 80th percentile of total U.S. sales. These 198 modules account for almost 80 percent of the total sales in grocery stores in the Nielsen data.[16]

The key variables for our empirical analysis are price and quantity. We define these variables at the level of module (m), store (r), and time (n), where a unit of time is a year-quarter. This requires aggregating weekly revenue and quantities sold seperately for each product to the quarterly level. A quarterly price is obtained by dividing quarterly revenue from the sales of product j by the number of units sold in that quarter. To address the concern that there may be compositional differences in price across stores due to different UPCs being offered, we follow Handbury and Weinstein (2015) and regress log quarterly price on UPC fixed effects and module-by-store-by-time fixed effects. The module-by-store-by-time fixed effects serve as the pre-tax price for the purpose of estimation. To measure quantity, we create a price-weighted quantity index based on the national price of products.[17] Specifically, for each product (j), store (r) and time (n), we multiply quantity purchased by the average national price (across all stores in our sample) of product j at time n, where the national price is an unweighted average. We then aggregate quantity across products within a module-by-store-by-time cell to arrive at a quantity measure that varies at the same level as the price index.

U.S. Sales Tax Exemptions and Rates We collect data on local (county and state) sales tax rates and tax exemptions from a variety of sources, including state laws, state regulations, and online brochures.[18] In general, tax exemptions are set by U.S. states and are module-specific. The general rule of thumb is that states exempt food products from taxation and tax non-food products.

[16]We limit to the top 20 percent of modules for computational reasons, and we have explored some of our main specifications in the full sample of modules and found very similar results (results not reported).

[17]This normalization by the national price allows us to more easily compare quantities across different goods and modules.

[18]All data sources used to determine the exemption status of products are listed in Appendix Table OA.2.

However, there are several important exceptions to this rule which are reported in Table 1. 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.[19] Third, in some cases where food is tax-exempt, there is a tax that applies at the product-module level. For example, prepared foods, soft drinks, and candy are subject to sales taxes in many states. Finally, some states exempt some non-food products from sales taxes. As a result, the effective sales tax rate varies by module (m), county (c), and time (n).[20]

There are two potential 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, in some cases, there is some discretion in how we assign a taxability status to each module, based on interpreting the text of a state's 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 we code these products as tax exempt since we cannot readily identify the real fruit juice content. 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 percent of the observations in our sample.

Overall, we are confident that we have measured sales tax rates with a high degree of accuracy. While sales tax exemptions are important for ensuring accurate measurement, the identifying variation in our emprical analysis comes primarily from changes in sales tax rates within counties over time. Changes in exemptions are very rare during our sample period, and all of our main specifi-

[19]Colorado, for example, allows each county to decide whether to subject food to the county-level portion of the sales tax rate.

[20]The Online Appendix shows the cross-sectional variation in sales tax rates and sales tax exemptions in our data. Appendix Figure OA.1 reports the total (state + county) sales tax rate in September 2008 and shows tax rates ranging from 0 in Montana, Oregon, New Hampshire and Delaware to a maximum rate of 9.75 percent in Tennessee. Appendix Figure OA.2 reports the food tax exemptions across states and shows that many of the states that tax food are located in either the South or the Midwest.

cations include module-by-state-by-time fixed effects, so any changes in state sales tax rates or tax exemptions (regardless of the set of modules affected) are absorbed into these fixed effects and thus not used for identification of the effects of sales taxes.

Matched Sample As a last step in constructing our analysis sample, we merge the tax data onto the Retail Scanner data. The stores in the Nielsen data are geolocated at the county level so we conduct the merge at the level of module (m), county (c) and time (n). To measure the sales tax rate by quarter of year, we use the tax rate effective at the mid-point of each quarter (February for quarter 1, May for quarter 2, etc). We have also tried using the quarterly average of monthly sales tax rates and found that our estimates were almost identical. Our final sample includes 8,652 grocery stores, and includes price, quantity and tax rates for 198 modules in 1,460 counties over 36 year-quarters.

5.2 Estimation Strategy

The Effect of Taxes on Prices and Quantity Our main specification is a "constant effects" model which can be derived from the model above by assuming that consumers have identical demand functions. We estimate the effect of sales taxes on consumer prices and quantity using two complementary regression models. The first model uses the full set of counties from the Neilsen Retail Scanner data using the following estimating equation:

$$\log y_{mrn} = \beta^y \log(1+\tau_{mcn})+\delta_{msn}+\delta_{mr}+\varepsilon_{mrn} \tag{2}$$

where the outcome y_{mrn} is either consumer prices $(p(1+\tau))$ or quantity (Q) for module m, store r and time n. The term τ_{mcn} is the sales tax rate that applies to module m in county c at time n. The terms δ_{msn} and δ_{mr} are module-by-state-by-time and module-by-store fixed effects, respectively. The identifying assumption is that changes in sales taxes do not change within counties in ways that are correlated with changes in consumer demand (conditional on the fixed effects). This model allows for arbitrary trends across states and modules and thereby relies on within-county-over-time variation in tax rates. The estimate β^y can be interpreted as the elasticity of prices or quantity with respect to taxes ($\beta^{p(1+\tau)}$ and β^Q, respectively).

The second regression model uses a subsample of counties and a "county border pair" research design, following Holmes (1998) and Dube, Lester and Reich (2010). For this analysis, we restrict the sample to stores located in contiguous counties 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 as they are contiguous with. The estimating equation is the following:

$$\log y_{mrn} = \beta^y \log(1+\tau_{mcn}) + \delta'_{mdn} + \delta'_{mr} + \varepsilon'_{mrn}. \tag{3}$$

where δ'_{mdn} and δ'_{mr} are module-by-border-pair-by-time and module-by-store fixed effects, respectively. This specification includes flexible trends for each module in each border pair. To estimate equation (3), the original dataset is rearranged by stacking all county pairs and weighting each store by the inverse of the number of times it is included in a border pair. In this regression model, the identifying assumption is that within a border pair, variation in tax rates for a given module over time is not correlated with other unobserved determinants that differentially affect one of the counties in the pair. One way this assumption could fail is if counties adjust their tax rates based on economic conditions within the border pair. To address this concern, we also report results in Appendix Table OA.3 in which we instrument the total tax rate with the state sales tax rate (and find similar results).

The main results from estimating equations (2) and (3) are reported in Panel A of Table 2. The first column uses the full sample, and the second column uses the "border pair" subsample. The first row reports results for log consumer prices. In column (1), the coefficient estimate $\widehat{\beta^{p(1+\tau)}} = 0.961$ (s.e. 0.045) indicates a large but incomplete amount of pass-through of taxes onto consumer prices.[21] The next row reports the estimate $\widehat{\beta^Q} = -0.668$ (s.e. 0.185), indicating a meaningful quantity response to tax changes. The results in column (2) show similar results using the county

[21]Classical measurement error in effective tax rates biases our estimates of $\beta^{p(1+\tau)}$ towards 1. Instrumental variable estimates of the effect of sales taxes on prices presented in Appendix Table OA.1 are slightly smaller than their corresponding border-sample OLS estimates, suggesting a small amount of attenuation bias.

border pair approach.

Tax salience parameter Since the main specification is a "constant effects'" specification with no heterogeneity across consumers in terms of demand responses, there is no heterogeneity in the tax salience parameter, θ_τ. In this setup, to estimate the tax salience parameter θ_τ, the effect of sales taxes on quantity needs to be scaled by the effect of price changes on quantity. To estimate the price elasticity of demand, we follow the recent literature on uniform pricing by retail chains and construct a store-level instrument based on the pricing of products of other stores in a given retail chain (DellaVigna and Gentzkow 2019). This instrumental variables strategy relates to earlier work by Hausman (1996) and Nevo (2001), and has been used in several recent papers (e.g., Atkin, Faber and Gonzalez-Navarro 2018 and Allcott et al. 2019).

Specifically, we construct an instrument z_{mrn} that is equal to the average log pre-tax price across all stores in the same retail chain excluding store r:

$$z_{mrn} = \frac{\sum_{x \in f} \log(p_{mxn}) - \log(p_{mrn})}{N_{fn} - 1}$$

where f denotes the retail chain to which store r belongs and N_{fn} is the number of stores in chain f at time n. This is a valid instrument under the assumption that chain-level prices predict "own" store prices, but are not correlated with unobserved store-level demand determinants. A threat to the validity of this instrument is that there are correlated demand shocks across stores within retail chains. To address this, we continue to include store-by-module fixed effects in all of our specifications. The inclusion of module fixed effects accounts for the fact that more expensive modules may reflect chains responding to strong demand for these modules. Intuitively, our identification is coming from differences in relative prices across modules and chains. To the extent that this variation is driven by differences in product-specific marginal costs across chains, differences in distribution costs across chains (such as supply-sourcing costs), or differences in bargaining power across chains, we can consistently estimate our elasticity of interest, since these supply-side instruments will identify the average price elasticity of demand. Intuitively, this approach requires that chains select store locations based on overall demand factors (that are common across modules), but not module-specific demand factors. In Appendix Table OA.4, we report the reduced-form relationships between this instrument and price and quantity. To further verify that our results are not contaminated by local module-specific demand shocks, we present corresponding estimates based on an alternative instrument that is equal to the average log pre-tax price across stores in the same chain excluding all stores located in county c, and we show that our estimates are insensitive to using this alternative choice of instrument.

Using the chain-level instrument, we estimate the price elasticity of demand using the following Two Stage Least Squares (2SLS) regression model:

$$\begin{aligned} \log(p(1+\tau)_{mrn}) &= \lambda z_{mrn} + \kappa'_{msn} + \kappa'_{mr} + \upsilon'_{mrn} \\ \log Q_{mrn} &= \alpha \log(p(1+\tau)_{mrn}) + \kappa_{msn} + \kappa_{mr} + \upsilon_{mrn} \end{aligned}$$

where the log consumer price, $\log(p(1+\tau)_{mrn})$, is instrumented with z_{mrn}. The κ and κ' terms correspond to the same set of fixed effects as in the regression models in the prior section. Panel B of Table 2 reports the 2SLS estimates of α. The price elasticity of demand estimate in the full sample is $\widehat{\alpha} = -1.202$ (s.e. 0.027), and for the border pair subsample the estimate is $\widehat{\alpha} = -1.223$ (s.e. 0.027). Both of these values are larger in magnitude than the estimated tax elasticity in Panel A, which suggests that consumers underreact to taxes relative to posted prices.

We next estimate the tax salience parameter θ_τ directly by plugging in each of the estimates in Panel A and Panel B of Table 2 using the formula in Lemma 2 evaluated at $t = 0$, which we re-arrange slightly to more closely line up with the empirical estimates:

$$\theta_\tau = \frac{(1-\rho_\tau)\,\tilde{\epsilon}_D + \tilde{\epsilon}_{D\tau}}{(1+\tau\rho_\tau)\,\tilde{\epsilon}_D} \tag{4}$$

Note that $\rho_\tau = d\log(p(1+\tau))/d\log(1+\tau)$ and corresponds to the estimate $\beta^{p(1+\tau)}$, $\tilde{\epsilon}_D \equiv \frac{d\log(Q)}{d\log(p(1+\tau))}$ and corresponds to the estimate α, and $\tilde{\epsilon}_{D\tau} \equiv \frac{d\log(Q)}{d\log(1+\tau)}$, which corresponds to the estimate β^Q. If there is complete pass-through ($\rho_\tau = 1$), then the "plug-in" estimate of θ_τ reduces to the ratio of the tax elasticity ($\tilde{\epsilon}_{D\tau}$) to the price elasticity ($\tilde{\epsilon}_D$) when $\tau = 0$. The formula accounts for the fact that when pass-through is incomplete and taxes are not fully salient, manipulating the actual after-tax price is not the same as manipulating the perceived price. Similar to other estimation approaches in the literature, our identification of θ_τ relies on consumers perceiving tax and price changes to be equally persistent, such that there is no difference in the degree of intertemporal substitution under full salience. Similarly, it requires that equivalent price and tax changes induce the same degree of substitution between product-modules.

Panel C of Table 3 reports our "plug-in" estimates of θ_τ using our reduced-form results and using $\tau = 0.036$, which is the sample average sales tax rate. We estimate $\widehat{\theta_\tau} = 0.575$ (s.e. 0.147) using the full sample and $\widehat{\theta_\tau} = 0.528$ (s.e. 0.130) using the border-pair subsample.[22] For comparison, Chetty, Looney and Kroft (2009) estimate $\widehat{\theta_\tau} = 0.35$ using a field experiment which posted tax-inclusive prices in a grocery store. Taubinsky and Rees-Jones (2018) and Morisson and Taubinsky (2020) conduct online shopping experiments in which participants face different tax rates on common household goods. Using experimental variation in tax rates along with a pricing mechanism used to elicit willingness to pay, they report ranges of experimental estimates of θ_τ between 0.23 and 0.54 and between 0.23 and 0.79, respectively.

As a robustness test, we consider an alternative method for calculating the tax elasticity and the price elasticity, as well as the associated value of θ_τ, in Appendix Table OA.6. In Panels A and B, we report the effect of taxes and of the price instrument on total expenditures.[23] We then back out the implied effect on quantity by subtracting the effect on prices (column 2) from the effect on expenditures (column 3). The implied values of the average tax salience parameter are $\widehat{\theta_\tau} = 0.552$ and $\widehat{\theta_\tau} = 0.491$ for the full sample and the border-pair subsample, respectively.

[22] Appendix Table OA.5 presents results based on alternative ways to account for spatial heterogeneity in consumption trends in our main sample. To account for county-level time-varying heterogenetity, we parameterize country-specific trends for each module as linear time trends (module-by-county-by-year-quarter fixed effects leave no residual variation in tax rates and therefore cannot be used). We also consider store-specific linear trends for each module. The tax and price elasticities under these alternative specifications are smaller than our preferred estimates and imply slightly lower values of θ_τ, ranging between 0.376 and 0.507. We note that the inclusion of module-by-state-by-year-quarter fixed effects in our preferred specification effectively shuts down variation from state-level tax rates, whereas county-module linear trends do not.

[23] Total expenditures on module m is equal to $\sum_{j \in m} (q_{jrn} \times p_{jrn})$, where j denotes a UPC. The effect on expenditures therefore captures both the effects on prices and on quantity.

6 Calibrations

In this section, we calibrate the incidence and marginal excess formulas for ad valorem taxes using the estimates in the previous section. To do this, we first recover the markup and the conduct parameter in several intermediate steps shown in the bottom of Table 4. We assume constant marginal costs and constant price elasticity of demand throughout this calibration exercise.

Using our estimates of ρ_τ and θ_τ, along with the pass-through expression, we recover an estimate of $v_q/(J\epsilon_{ms}) = 0.041$ by exploiting the fact that the elasticity of marginal surplus is equal to the inverse of the price elasticity of demand under constant elasticity of demand; i.e., $\epsilon_{ms} = 1/\epsilon_D$. Next, in order to estimate the markup $(p-mc)/p$, we translate $v_q/(J\epsilon_{ms})$ into $v_q/(J\epsilon_D)$, and since the latter determines the markup, we estimate $(p-mc)/p = 0.028$.[24] Our last intermediate step estimates $v_q/J = 0.034$.

With the estimated markup and conduct parameters in hand, we can calibrate the incidence and marginal excess burden formulas for ad valorem taxes using the results in Table 3. Extending the incidence formula for ad valorem taxes to allow for heterogeneity in θ_τ results in the following:

$$I = \frac{\rho_\tau(1+\tau) + (1-\theta_\tau)\tau\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)Var(\theta_\tau)}{\left(1-\frac{\nu_q}{J}\right)(1-\rho_\tau) + \frac{\nu_q}{J}\theta_\tau\left(1+\tau\rho_\tau\right)} \tag{5}$$

In Table 3, column (1) assumes no heterogeneity in θ_τ, while column (2) illustrates sensitivity to heterogeneity in θ_τ by assuming that the variance of θ_τ is equal to 0.25.[25] In column (1), we calculate $I = 17.051$, which suggests that much of the incidence of sales taxes falls on consumers.

[24]Grocery stores operate on relatively low profit margins; industry analyst Jeff Cohen recently said that "It's a very competitive industry ... grocery stores can only slightly mark up the prices for their products." https://www.marketplace.org/2013/09/12/groceries-low-margin-business-still-highly-desirable/.

[25]The empirical model assumed "constant effects" and thus ignored heterogeneity across consumers. The sensitivity analysis in column (2) can thus be interpreted as allowing for heterogeneity across consumers in tax salience (as accommodated by the theory), but continuing to assume that all consumers would respond similarly when fully optimizing (Assumption 1). To accommodate richer consumer heterogeneity in the empirical analysis requires more detailed individual-level data than the retail scanner data that we use in this paper. Also, in calibrating the incidence formlua we assume a value for $(1/p)Var(\theta_\tau)$, which normalizes the consumer heterogeneity in θ_τ by price and avoids having to calibrate a value for the pre-tax price in any of our calibrations. To put the variance of θ_τ of 0.25 in context, consider the special case where $\theta_\tau \in \{0,1\}$; i.e., some consumers fully optimize, while others are completely inattentive to taxes. Since θ_τ is binary, an average θ_τ of 0.575 (i.e., the share of consumers fully optimizing) implies a variance of 0.24. By comparison, Taubinsky and Rees-Jones (2018) report a lower bound estimate of the variance of θ_τ around 0.1. Since the variance of θ_τ enters the welfare and incidence formula linearly, using a lower value of the variance in our calibrations would naturally bring the incidence and marginal excess burden estimates reported in column (2) closer to the values in column (1) that assume no heterogeneity in tax salience across consumers.

In column (2), we allow for heterogeneity in tax salience, and we find this reduces the incidence on consumers to $I = 16.857$. Ignoring salience entirely ($\theta_\tau = 1$) but holding fixed the estimated markup at 0.028, we find $I = 13.701$ (column (3)). Lastly, column (4) continues to assume full optimization, but recalibrates the markup assuming $\theta_\tau = 1$. This is important to consider since different assumptions on the value of θ_τ affect the incidence formula directly, but also indirectly since it affects the estimated markup. In this case, we find $I = 17.124$, showing that the incidence on consumers is *greater* when consumers are more attentive to the tax, and contrasts with the intuition from Chetty, Looney and Kroft (2009). In the case of perfect competition, the incidence of the tax is fully born by consumers regardless of the magnitude of θ_τ under our assumption of constant marginal costs. These results demonstrate how salience and imperfect competition interact to determine tax incidence.

Turning to marginal excess burden, we extend the ad valorem marginal excess burden formula to allow for heterogeneity in θ_τ and scale the expression so that it represents the change in welfare as a percentage of total revenue. This results in the following:

$$\frac{d\widetilde{W}}{d\tau} \equiv \frac{(1+\tau)}{pQ}\frac{dW}{d\tau} = \left(\frac{p-mc}{p} + \theta_\tau \tau\right)\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)Var(\theta_\tau) \qquad (6)$$

Using the sample average tax rate of 3.6 percent for τ, we find $d\widetilde{W}/d\tau = -0.033$ (column 1). This implies that the marginal excess burden is about 3.3 percent of total revenue. The formula in Chetty, Looney and Kroft (2009) gives an estimate of $d\widetilde{W}/d\tau = -0.014$ (column 1), while the standard Harberger formula assuming full optimization gives an estimate of $d\widetilde{W}/d\tau = -0.024$ (column 3). Interestingly, both estimates are smaller than the main estimate in column (1), suggesting that accounting for both salience and imperfect competition leads to a change in welfare that is larger than the estimates implied by a standard analysis. Allowing for heterogeneity in θ_τ across consumers increases the welfare cost of taxation to $d\widetilde{W}/d\tau = -0.043$ (column 2). Under perfect competition, allowing for heterogeneity in θ_τ increases the welfare cost of taxation by the same amount as it does under imperfect competition (holding constant the other parameters).

Ignoring salience ($\theta_\tau = 1$ for all consumers) while holding fixed the markup increases the welfare cost of taxation (in magnitude) by 1 percentage point to -0.043, which is the exact same change as we move from the Chetty, Looney and Kroft (2009) formula to the standard Harberger formula. This illustrates the similar way that tax salience affects welfare under different market structures.

Lastly, column (4) continues to assume full optimization, but recalibrates the markup accordingly (assuming $\theta_\tau = 1$). In this case, the markup falls to 1.6 percent, and the implied $d\widetilde{W}/d\tau = -0.035$, which is smaller than the estimate in column (3), but still larger in magnitude than the standard Harberger formula. We note that although the estimated markup appears small, it has a first-order impact on welfare that exceeds that of tax salience. Under imperfect tax salience ($\theta_\tau = 0.575$), imperfect competition raises the welfare cost of sales taxes by 2 percentage points, from -0.014 to -0.033. Overall, results in Table 4 show the subtle impact of salience on the welfare consequences of sales taxes, since salience both directly impacts the welfare formula through $\theta_\tau \tau$, but also affects it indirectly through our inference on the markup. Also, heterogeneity in tax salience increases the marginal excess burden but decreases the incidence on consumers.

We assess the robustness of the calibration results in a number of dimensions. Appendix Table OA.7 reports all of the results in Table 3 using the county border pair subsample instead of the full sample of counties. Since the reduced-form effects are fairly similar, it is not surprising that the incidence and welfare results are broadly similar, although the difference between the Harberger formula and the full welfare formula allowing for imperfect competition and tax salience is reduced somewhat. This is because using the county border pair results we find that the attenuating effect of the tax salience parameter largely offsets the increase in magnitude of welfare change due to imperfect competition. In Appendix Table OA.8, we show senstivity to alternative values of the elasticity of marginal surplus. For the main results in Table 3, we assume that this elasticity is equal to the inverse of the price elasticity of demand. Alternative functional form assumptions would lead to different relationships between these parameters. Since we do not have sufficient data to estimate the elasticity of marginal surplus directly, we instead show sensitivity across different values of this parameter. Varying this parameter by roughly 50 percent in either direction does not change the main qualitative conclusions from our main results that the incidence largely falls on consumers, the incidence is increasing in the tax salience parameter, and the Harberger formula understates the welfare change relative to the general welfare formula that allows for both tax salience and imperfect competition.

7 Conclusion

This paper develops new formulas for the welfare effects of commodity taxation in a model with heterogeneous consumers featuring imperfect competition and tax salience. We find important interactions between salience and the degree of competition for tax incidence, but no direct interactions for efficiency analysis. We also show that heterogeneity in inattention matters for incidence under all market structures, including perfect competition.

We estimate the inputs into the formulas using Nielsen Retail Scanner data and detailed sales tax data. We find nearly-complete pass-through of sales taxes onto prices and meaningful effects of taxes on quantity. We also find that consumers substantially "underreact" to taxes, with a tax elasticity about 53 to 58 percent of the price elasticity. We use our formulas to calibrate a markup around 3 percent, which is consistent with grocery stores operating with fairly low profit margins.

We use these estimates to calibrate our new incidence and efficiency formulas, and we find lower incidence on consumers (as compared to perfect competition) and that greater attention to the tax can lead to consumers bearing a higher share of the burden of the tax. Accounting for heterogeneity in consumers' inattention to taxes further lowers the incidence of taxes on consumers. Turning to welfare, we find the standard marginal excess burden formula substantially understates the welfare costs of commodity taxation, even after accounting for consumers' underreaction due to salience effects. While we estimate substantial underreaction to taxes alongside a fairly small markup (and thus fairly small depature from perfect competition), our calibration results suggests that both are important for welfare analysis. Ignoring imperfect competition but allowing for salience effects leads to a substantial underestimate of the marginal excess burden, while ignoring salience effects but allowing for imperfect competition leads to an overestimate of the marginal excess burden by roughly the same magnitude. As a result, we conclude that both imperfect competition and tax salience are important factors to consider together when analyzing the incidence and efficiency consequences of commodity taxation. Focusing on either one in isolation will, in some circumstances, lead to misleading estimates.

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Table 1: Sales Tax Exemptions for Food and Non-Food Products Across States

Panel A: Food Modules

Module	Average Store-Level Expenditure Share	States taxing all food	States taxing module at reduced	States taxing module at full rate (but otherwise exempting
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,

Panel B: Non-Food Modules

Module	Average Store-Level Expenditure Share	States with no sales tax	States exempting module	States 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,	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: Tax exemption status as in September 2008 for selected list of modules. The list only includes modules in our analysis sample.

Table 2

Estimates of Tax Elasticities, Price Elasticity of Demand, and Tax Salience Parameter

Sample:	Full Sample	County Border Pair Subsample
	(1)	(2)
Panel A: Reduced-form OLS Estimates of the Effects of Sales Taxes on Consumer Prices and Quantity		
$d\log(p(1+\tau))/d\log(1+\tau)$	0.961	0.986
	(0.045)	(0.016)
$d\log(Q)/d\log(1+\tau)$	-0.668	-0.650
	(0.185)	(0.084)
Panel B: 2SLS Estimates of the Price Elasticity of Demand		
$d\log(Q)/d\log(p)$	-1.202	-1.223
	(0.027)	(0.027)
Panel C: "Plug-in" Estimate of the Tax Salience Parameter		
θ	0.575	0.528
	(0.147)	(0.130)
Specification:		
Store × Module fixed effects	y	y
Module × Year-Quarter fixed effects	y	y
Module × State × Year-Quarter fixed effects	y	
Module × Border Pair × Year-Quarter fixed effects		y
N	53,895,446	33,749,157

Notes: This table reports estimates of the effects of sales taxes, of the price elasticity of demand, and of the tax salience parameter. In Panel A, the independent variable is quarterly sales tax rate of module *m* in county *c* in state *s*. One observation is a module in a store in a given quarter. Consumer prices $p(1+\tau)$ are tax inclusive. The Retail Scanner data is restricted to modules above the 80th percentile of the national distribution of sales. In Panel B, the reported coefficients are 2SLS estimates of the effect of consumer prices on quantity sold, where prices are instrumented with leave-self-out chain-level average prices. In Panel C, we report the estimate of the tax salience parameter. For this parameter, standard errors are based on 100 bootstrap replications. All standard errors in this table are clustered at the state-module level and are reported in parentheses. In column (1), the sample includes our full sample of stores and the regression model includes module-by-store and module-by-quarter-by-state fixed effects. In column (2), the sample is restricted to stores in border counties and the regression model includes module-by-store and module-by-border-pair-by-year-quarter fixed effects, where border pairs denote pairs of contiguous counties on opposite sides of a state border. In column (2), observations are weighted by the inverse of the number of times a store appears in the data.

Table 3

Calibration of Incidence and Marginal Excess Burden Formulas

Tax salience parameter (θ):	Plug-in estimate of tax salience parameter, E[θ] = 0.575		Full salience, θ = 1	
Heterogeneity in θ:	$(1/p)\mathrm{Var}(\theta) = 0$	$(1/p)\mathrm{Var}(\theta) = 0.25$	No heterogeneity, $(1/p)\mathrm{Var}(\theta) = 0$	
Implied markup:	Baseline markup	Same markup from (1)	Same markup from (1)	Re-calibrate markup under $\theta = 1$
	(1)	(2)	(3)	(4)
Panel A: Incidence and Marginal Excess Burden Formulas				
Incidence (I)				
General formula (imperfect salience, imperfect competition): $(\rho_\tau(1+\tau) + (1-\theta)\tau\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)\mathrm{Var}(\theta)) / ((1-v/J)(1-\rho_\tau) + (v/J)\theta(1+\tau\rho_\tau))$	17.051	16.857	13.701	17.124
Incidence under perfect competition (for $0 < \theta \leq 1$)	∞	∞	∞	∞
Marginal Excess Burden ($d\tilde{W}/d\tau$)				
General formula (imperfect salience, imperfect competition): $d\tilde{W}/d\tau = ((p-mc)/p + \theta\tau)\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)\mathrm{Var}(\theta)$	-0.033	-0.043	-0.043	-0.035
CLK / Taubinsky Rees-Jones formulas (perfect competition): $d\tilde{W}/d\tau = \theta\tau\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)\mathrm{Var}(\theta)$	-0.014	-0.025	-0.024	
Panel B: Inputs and Intermediate Estimates Needed to Calibrate Formulas				
Inputs:				
Average tax rate, τ	0.036	0.036	0.036	0.036
Price Elasticity, $\tilde{\epsilon}_D \equiv \partial\log(Q)/\partial\log(p)$	-1.202	-1.202	-1.202	-1.202
Tax Pass-Through, $\rho_\tau \equiv d\log(p(1+\tau))/d\log(1+\tau)$	0.961	0.961	0.961	0.961
Tax Elasticity, $\tilde{\epsilon}_{D\tau} \equiv d\log(Q)/d\log(1+\tau)$	-0.668	-0.668	-0.668	-0.668
Tax Salience Parameter, θ				
Implied "Plug-In" Estimate of E[θ]	0.575	0.575		
Assuming full salience (E[θ] = 1)			1.00	1.00
$(1/p)\mathrm{Var}(\theta)$	0.00	0.25	0.00	0.00
Intermediate estimates:				
Implied estimate of $v_q/(J\epsilon_{ms})$	0.041	0.041		0.023
Implied markup $(p-mc)/p$	0.028	0.028		0.016
Implied estimate of v_q/J ($v_q/J = 0$ is perfect competition, $v_q/J = 1$ is perfect collusion)	0.034	0.034		0.019

Notes: This table reports calibrations of the tax incidence and marginal excess burden formulas. The results of these calibrations are shown in Panel A. Panel B presents the value of the input parameters taken from Table 2 column (1), as well as estimates of intermediate parameters. In column (1), the incidence and marginal excess burden formulas are implemented with no restrictions. In column (2) we allow for heterogeneity in salience parameter. In column (3), we use estimates of the markup based on the tax salience parameter reported in column (1), but assume full salience elsewhere in the formulas. In column (4), full salience is assumed throughout, including when calculating the markup.

Online Appendix for "Salience and Taxation with Imperfect Competition"

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Proofs

Proof of Lemma 1

Proof. Note that

$$\begin{aligned}
\epsilon_{Dt} &= \frac{dD(p(t),t)}{dt}\frac{p+t}{q(t)} \\
&= \frac{p+t}{q(t)}\int \frac{\partial D_i}{\partial p}(p(t),t) \quad \frac{dp}{dt} + \theta_i \Big) di \\
&= \frac{p+t}{q(t)} \quad (\rho - 1)\frac{\partial D}{\partial p} + \int \frac{\partial D_i}{\partial p}(p(t),t)\theta_i di \Big) \\
&= \frac{p+t}{q(t)}\left((\rho - 1 + \mathbb{E}(\theta_i))\frac{\partial D}{\partial p} + Cov\left(\theta_i, \frac{\partial D_i(p,t)}{\partial p}\right)\right) \\
&= -(\mathbb{E}(\theta_i) + \rho - 1)\epsilon_D + \frac{p+t}{q(t)}Cov\left(\theta_i, \frac{\partial D_i(p,t)}{\partial p}\right)
\end{aligned}$$

Finally, under assumption 1 $\frac{\partial D_i}{\partial p}(p(t),t)$ is constant in i and so $Cov\left(\theta_i, \frac{\partial D_i(p,t)}{\partial p}\right) = 0$ □

Proof of Proposition 1

Proof. Let the market be perfect competition. Consumer surplus can be expressed as

$$CS_i = \int_0^{q_i} wtp_i(s)ds - (p+t)q_i$$

Given $\rho \equiv 1 + \frac{dp}{dt}$, we have

$$\begin{aligned}\frac{dCS_i}{dt} &= wtp_i(q_i)\frac{dq_i}{dt} - \rho q_i - (p+t)\frac{dq_i}{dt} \\ &= (p+\theta_i t)\frac{dq_i}{dt} - \rho q_i - (p+t)\frac{dq_i}{dt} \\ &= -\rho q_i - (1-\theta_i)t\frac{dq_i}{dt}\end{aligned}$$

where the second equality follows from the fact that $wtp_i(q_i) = p + \theta_i t$, then

$$\begin{aligned}\frac{dCS}{dt} &= \int \frac{dCS_i}{dt} di \\ &= -\rho \mathbb{E}(q_i) - t\mathbb{E}\left((1-\theta_i)\frac{dq_i}{dt}\right) \\ &= -\rho q - (1-\mathbb{E}(\theta_i))t\frac{dq}{dt} + tCov\left(\theta_i, \frac{dq_i}{dt}\right)\end{aligned}$$

For the tax revenue, we have

$$\frac{dR}{dt} = q + t\frac{dq}{dt}$$

For producer surplus, we have

$$\frac{dPS}{dt} = -(1-\rho)q$$

Note that

$$\begin{aligned}\frac{dq}{dt} &= \int \frac{dq_i}{dt} di \\ &= \int \frac{\partial D_i}{\partial p}\left(\frac{dp}{dt} + \theta_i\right) di \\ &= \mathbb{E}\left(\frac{\partial D_i}{\partial p}\right) * (\rho - 1 + \mathbb{E}(\theta_i)) + Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)\end{aligned}$$

Then we have

$$\begin{aligned}\rho &= \frac{dp}{dt} + 1 \\ &= 1 - \left(1 - \frac{1}{1 + \frac{\epsilon_D}{\epsilon_S}\frac{p}{p+t}}\right)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right) \\ &= 1 - (1-\omega)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right)\end{aligned}$$

where $\omega = \frac{1}{1+\frac{\epsilon_D}{\epsilon_S}\frac{p}{p+t}}$

Using Lemma 1, we have

$$\begin{aligned}I &= \frac{-\rho q - (1-\mathbb{E}(\theta_i))t\frac{dq}{dt} + tCov\left(\theta_i, \frac{dq_i}{dt}\right)}{-(1-\rho)q} \\ &= \frac{\rho}{1-\rho} + \frac{1-\mathbb{E}(\theta_i)}{1-\rho}\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{q(1-\rho)}Cov\left(\theta_i, \frac{dq_i}{dt}\right)\end{aligned}$$

Finally, the marginal excess burden of a unit tax is calculated by summing up the incidence on consumers, producers, and government. □

Proof of Proposition 2

Proof. Let the firm be a monopoly in the market. The incidence of a tax on consumers is the same as in the perfect competitive market, since the incidence does not depend on the firm's behavior. Similarly, the incidence on the government is the same as in the perfect competitive market.

Using Lerner's rule, we have in monopoly that $p - mc(q) = -mwtp(q)q$. The incidence on the producer is then

$$
\begin{aligned}
\frac{dPS}{dt} &= \frac{dp}{dt}q + [p - mc(q)]\frac{dq}{dt} \\
&= (\rho - 1)q - mwtp(q)q\frac{dq}{dt} \\
&= (\rho - 1)q - q\frac{\int \frac{dq_i}{dt}di}{\frac{\partial D}{\partial p}} \\
&= (\rho - 1)q - q\frac{\int \frac{\partial D_i}{\partial p}\left(\frac{dp}{dt} + \theta_i\right)di}{\frac{\partial D}{\partial p}} \\
&= (\rho - 1)q - q\left[\frac{dp}{dt} + \frac{\int \theta_i \frac{\partial D_i}{\partial p}di}{\frac{\partial D}{\partial p}}\right] \\
&= -q\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right)
\end{aligned}
$$

Recall thar marginal surplus is $ms(q) = -mwtp(q)q$. Furthermore, define $MS(q,t) = -\frac{q}{\frac{\partial D}{\partial p}(p(t),t)} = \frac{ms(q)}{mwtp(q(t)) * \frac{\partial D}{\partial p}(p(t),t)}$, then $MS(q,0) = ms(q)$. Let $MS_t = \frac{\partial MS}{\partial t}$, and let $\epsilon_{ms} = \frac{MS}{MS_q q}$, we have

$$
p - mc(q) = MS(q,t)
$$

Therefore

$$
\begin{aligned}
\frac{dp}{dt} &= (MS_q(q,t) + mc'(q))\frac{dq}{dt} + MS_t \\
&= (MS_q(q,t) + mc'(q))\left(\frac{\partial D}{\partial p}\left(\frac{dp}{dt} + \mathbb{E}(\theta_i)\right) + Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)\right) + MS_t
\end{aligned}
$$

Then we have

$$
\begin{aligned}
\rho &= \frac{dp}{dt} + 1 \\
&= 1 + \frac{(ms'(q) + mc'(q))\left(\frac{\partial D}{\partial p}\mathbb{E}(\theta_i) + Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)\right) + MS_t}{1 - \frac{\partial D}{\partial p}\left(ms'(q) + mc'(q)\right)} \\
&= 1 + \left(\frac{1}{1 - \frac{\partial D}{\partial p}\left(ms'(q) + mc'(q)\right)} - 1\right)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right) + \frac{MS_t}{1 - \frac{\partial D}{\partial p}\left(ms'(q) + mc'(q)\right)} \\
&= 1 - \left(1 - \frac{1}{1 + \frac{\epsilon_D \frac{p}{p+t} - 1}{\epsilon_S} + \frac{1}{\epsilon_{ms}}}\right)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right) + \frac{MS_t}{1 - \frac{\partial D}{\partial p}\left(ms'(q) + mc'(q)\right)} \\
&= 1 - (1 - \omega)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right) + \omega MS_t
\end{aligned}
$$

where $\omega = \frac{1}{1 + \frac{\epsilon_D \frac{p}{p+t} - 1}{\epsilon_S} + \frac{1}{\epsilon_{ms}}}$.

The incidence of the tax is then:

$$
\begin{aligned}
I &= \frac{-\rho q - (1 - \mathbb{E}(\theta_i)) t \frac{dq}{dt} + t Cov\left(\theta_i, \frac{dq_i}{dt}\right)}{-q * \left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial D_i}{\partial p}\right)}{\frac{\partial D}{\partial p}}\right)} \\
&= \frac{\epsilon_D}{\frac{p+t}{q}\mathbb{E}\left(\theta_i \frac{\partial D_i}{\partial p}\right)}\left(\rho + (1 - \mathbb{E}(\theta_i))\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{q} Cov\left(\theta_i(p,t), \frac{dq_i}{dt}\right)\right)
\end{aligned}
$$

The marginal excess burden of the tax is calculated by summing up the incidence on consumers, producers, and government. □

Derivation of Marginal Surplus Remark

Let $MS(q,t) = \frac{ms(q)}{mwtp(q(t)) * \frac{\partial D}{\partial p}(p(t),t)}$, then $MS(q,0) = ms(q)$, and $MS(q(t),t) = \frac{-mwtp(q(t))q(t)}{mwtp(q(t)) * \frac{\partial D}{\partial p}(p(t),t)} = -\frac{q(t)}{\frac{\partial D}{\partial p}(p(t),t)}$. If $MS_t = \frac{\partial MS}{\partial t}$ then:

$$MS_t = \frac{-ms(q)}{\left(mwtp(q(t)) * \frac{\partial D}{\partial p}(p(t),t)\right)^2} \left(wtp''(q(t))q'(t) * \frac{\partial D}{\partial p}(p(t),t) + wtp'(q(t)) * \frac{\partial}{\partial t}\left(\frac{\partial D}{\partial p}(p(t),t)\right)\right)$$

$$= \frac{-ms(q)}{\left(mwtp(q(t)) * \frac{\partial D}{\partial p}(p(t),t)\right)^2} \left(wtp''(q(t))q'(t) * \frac{\partial D}{\partial p}(p(t),t) + wtp'(q(t)) * \int \frac{\partial}{\partial t}\left(\frac{\partial D_i}{\partial p}(p(t)+\theta_i t, 0)\right) di\right)$$

$$= \frac{-ms(q)}{\left(mwtp(q(t)) * \frac{\partial D}{\partial p}(p(t),t)\right)^2} *$$

$$\left(wtp''(q(t))q'(t) * \frac{\partial D}{\partial p}(p(t),t) + wtp'(q(t)) * \int \frac{\partial^2 D_i}{\partial p^2}(p(t)+\theta_i t, 0) * \left(\frac{dp}{dt} + \theta_i\right) di\right)$$

$$= \frac{-q}{mwtp(q)\left(\frac{\partial D}{\partial p}\right)^2} \left(wtp''(q) \frac{\partial D}{\partial p}\frac{dq}{dt} + mwtp(q)\left[\frac{dp}{dt}\int \frac{\partial^2 D_i}{\partial p^2} di + \int \left(\frac{\partial^2 D_i}{\partial p^2} * \theta_i\right) di\right]\right)$$

$$= \frac{-q}{mwtp(q)\left(\frac{\partial D}{\partial p}\right)^2} \left(wtp''(q) \frac{\partial D}{\partial p}\frac{dq}{dt} + mwtp(q)\left[\frac{\partial^2 D}{\partial p^2}\left(\frac{dp}{dt} + \bar{\theta}\right) + Cov\left(\frac{\partial^2 D_i}{\partial p^2}, \theta_i\right)\right]\right)$$

$$\approx \frac{-q}{\left(\frac{\partial D}{\partial p}\right)^2} Cov\left(\frac{\partial^2 D_i}{\partial p^2}, \theta_i\right)$$

Note that under Assumption 1 the second derivatives are 0 and so $MS_t = 0$. Also for the model with fixed θ it is easy to show that $wtp' = \left(\frac{\partial D}{\partial p}\right)^{-1}$ implies $wtp''(q)\frac{dq}{dt} = -\frac{mwtp(q)}{\frac{\partial D}{\partial p}}\frac{\partial^2 D}{\partial p^2}\left(\frac{dp}{dt} + \bar{\theta}\right)$ so $MS_t = 0$.

Proof of Proposition 3

Proof. Let the market be symmetric imperfect competition with J products $j = 1, \ldots, J$ and the market conduct parameter $\nu_p = \frac{\partial p_k}{\partial p_j}$ $(k \neq j)$.

$$CS_i = \int_0^{Q_i} wtp_i(s)ds - (p+t)Q_i$$

Given $\rho \equiv 1 + \frac{dp}{dt}$, we have

$$\begin{aligned} \frac{dCS_i}{dt} &= wtp_i(Q_i)\frac{dQ_i(p(t),t)}{dt} - \rho Q_i - (p+t)\frac{dQ_i(p(t),t)}{dt} \\ &= (p+\theta_i t)\frac{dQ_i(p(t),t)}{dt} - \rho Q_i - (p+t)\frac{dQ_i(p(t),t)}{dt} \\ &= -\rho Q_i - (1-\theta_i)t\frac{dQ_i(p(t),t)}{dt} \end{aligned}$$

where the second equality follows from the fact that $wtp_i(Q_i) = p + \theta_i(p,t)t$, then

$$
\begin{aligned}
\frac{dCS}{dt} &= \int \frac{dCS_i}{dt} di \\
&= -\rho\mathbb{E}(Q_i) - t\mathbb{E}\left((1-\theta_i)\frac{dQ_i(p(t),t)}{dt}\right) \\
&= -\rho Q - (1-\mathbb{E}(\theta_i))t\frac{dQ(p(t),t)}{dt} + tCov\left(\theta_i, \frac{dQ_i(p(t),t)}{dt}\right)
\end{aligned}
$$

For the tax revenue, we have

$$
\frac{dR}{dt} = Q + t\frac{dQ(p(t),t)}{dt}
$$

For producer surplus, taking the derivative of $PS = pQ - Jc(q)$ with respect to t, we have

$$
\begin{aligned}
\frac{dPS}{dt} &= (\rho-1)Q + J(p - mc(q))\frac{dq}{dt} \\
&= (\rho-1)Q + \frac{\nu_q}{J\epsilon_D}\frac{dQ(p(t),t)}{dt}p \\
&= (\rho-1)Q - \frac{\nu_q}{J}Q\frac{dQ(p(t),t)}{dt}\frac{1}{\frac{\partial Q}{\partial p}} \\
&= (\rho-1)Q - \frac{\nu_q}{J}Q\frac{\int \frac{dQ_i(p(t),t)}{dt}di}{\frac{\partial Q}{\partial p}} \\
&= (\rho-1)Q - \frac{\nu_q}{J}Q\frac{\int \frac{\partial Q_i}{\partial p}\left(\frac{dp}{dt}+\theta_i\right)di}{\frac{\partial Q}{\partial p}} \\
&= (\rho-1)Q - \frac{\nu_q}{J}Q\left[\frac{dp}{dt} + \frac{\int \theta_i \frac{\partial Q_i}{\partial p}di}{\frac{\partial Q}{\partial p}}\right] \\
&= -\left(1-\frac{\nu_q}{J}\right)[Q(1-\rho)] - \frac{\nu_q}{J}\left[Q\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right)\right]
\end{aligned}
$$

The second equality comes from the Lerner condition $\frac{p-mc(q)}{p} = \frac{\nu_q}{J\epsilon_D}$, and the fifth equation comes from $\frac{dQ_i(p(t),t)}{dt} = \frac{\partial Q_i}{\partial p}\left(\frac{dp}{dt}+\theta_i\right)$.

Also note that

$$
\begin{aligned}
\frac{dQ(p(t),t)}{dt} &= \int \frac{dQ_i(p(t),t)}{dt}di \\
&= \int \frac{\partial Q_i}{\partial p}\left(\frac{dp}{dt}+\theta_i\right)di \\
&= \mathbb{E}\left(\frac{\partial Q_i}{\partial p}\right)(\rho - 1 + \mathbb{E}(\theta_i)) + Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)
\end{aligned}
$$

Now, to obtain the formula for pass-through, from Lerner condition we have

$$p - mc(Q) = -\frac{\nu_q}{J}\frac{Q}{\frac{\partial Q}{\partial p}}$$

Recall thar marginal surplus is $ms(Q) = -mwtp(Q)Q$. Furthermore, define $MS(Q,t) \equiv -\frac{Q}{\frac{\partial Q}{\partial p}(p(t),t)} = \frac{ms(Q)}{mwtp(Q(t))*\frac{\partial Q}{\partial p}(p(t),t)}$, then $MS(Q,0) = ms(Q)$. Let $MS_t = \frac{\partial MS}{\partial t}$, and let $\epsilon_{ms} = \frac{MS}{MS_Q Q}$, we have

$$p - mc(Q) = \frac{\nu_q}{J} MS(Q,t)$$

Therefore

$$\begin{aligned}\frac{dp}{dt} &= \left(\frac{\nu_q}{J} MS_Q(Q,t) + mc'(Q)\right)\frac{dQ(p(t),t)}{dt} + \frac{\nu_q}{J} MS_t \\ &= \left(\frac{\nu_q}{J} MS_Q(Q,t) + mc'(Q)\right)\left(\frac{\partial Q}{\partial p}\left(\frac{dp}{dt} + \mathbb{E}(\theta_i)\right) + Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)\right) + \frac{\nu_q}{J} MS_t\end{aligned}$$

and

$$\frac{dp}{dt}\left[1 - \frac{\partial Q}{\partial p}\left(\frac{\nu_q}{J} MS_Q(Q,t) + mc'(Q)\right)\right] =$$
$$\left(\frac{\nu_q}{J} MS_Q(Q,t) + mc'(Q)\right)\left(\frac{\partial Q}{\partial p}\left(\mathbb{E}(\theta_i)\right) + Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)\right) + \frac{\nu_q}{J} MS_t$$

Then we have

$$
\begin{aligned}
\rho &= \frac{dp}{dt} + 1 \\
&= 1 + \frac{\left(\frac{\nu_q}{J} ms'(Q) + mc'(Q)\right)\left(\frac{\partial Q}{\partial p}\mathbb{E}(\theta_i) + Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)\right) + \frac{\nu_q}{J} MS_t}{1 - \frac{\partial Q}{\partial p}\left(\frac{\nu_q}{J} ms'(Q) + mc'(Q)\right)} \\
&= 1 + \left(\frac{1}{1 - \frac{\partial Q}{\partial p}\left(\frac{\nu_q}{J} ms'(Q) + mc'(Q)\right)} - 1\right)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right) \\
&+ \frac{\frac{\nu_q}{J} MS_t}{1 - \frac{\partial Q}{\partial p}\left(\frac{\nu_q}{J} ms'(Q) + mc'(Q)\right)} \\
&= 1 - \left(1 - \frac{1}{1 + \frac{\epsilon_D - \frac{\nu_q}{J}}{\epsilon_S} + \frac{\frac{\nu_q}{J}}{\epsilon_{ms}}}\right)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right) \\
&+ \frac{\frac{\nu_q}{J} MS_t}{1 - \frac{\partial Q}{\partial p}\left(\frac{\nu_q}{J} ms'(Q) + mc'(Q)\right)} \\
&= 1 - (1 - \omega)\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right) + \omega\frac{\nu_q}{J} MS_t
\end{aligned}
$$

where $\omega = \frac{1}{1 + \frac{\epsilon_D - \frac{\nu_q}{J}}{\epsilon_S} + \frac{\frac{\nu_q}{J}}{\epsilon_{ms}}}$.

The incidence of the tax is then:

$$
\begin{aligned}
I &= \frac{-\rho Q - (1 - \mathbb{E}(\theta_i)) t \frac{dQ}{dt} + tCov\left(\theta_i, \frac{dQ_i(p(t), t)}{dt}\right)}{-\left(1 - \frac{\nu_q}{J}\right)[Q(1-\rho)] - \frac{\nu_q}{J}\left[Q\left(\mathbb{E}(\theta_i) + \frac{Cov\left(\theta_i, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right)\right]} \\
&= \frac{\rho + (1 - \mathbb{E}(\theta_i))\frac{t}{p+t}\epsilon_{Dt} - \frac{t}{Q} Cov\left(\theta_i, \frac{dQ_i(p(t), t)}{dt}\right)}{(1-\rho)\left(1 - \frac{\nu_q}{J}\right) + \frac{\nu_q}{J}\frac{\mathbb{E}\left(\theta_i \frac{\partial Q_i}{\partial p}\right)}{\mathbb{E}\left(\frac{\partial Q_i}{\partial p}\right)}}
\end{aligned}
$$

The marginal excess burden of the tax is calculated by summing up the incidence on consumers, producers, and government. □

Proof of Lemma 2

Proof. Observe

$$\begin{aligned}
\epsilon_{D\tau} &= \frac{dQ}{d\tau}\frac{p(1+\tau)+t}{Q} \\
&= -\epsilon_D * \left((1+\tau)\frac{dp}{d\tau} + p\right) \\
&= -\epsilon_D * \frac{p}{1+\tau}\left((1+\theta_\tau\tau)\left(\frac{1}{p}(1+\tau)\frac{\partial p}{\partial \tau} + 1\right) + \theta_\tau - 1\right) \\
&= -\epsilon_D * \frac{p}{1+\tau}\left((1+\theta_\tau\tau)\,\rho_\tau + \theta_\tau - 1\right)
\end{aligned}$$

Solving for θ_τ we obtain:

$$\theta_\tau = \frac{(1-\rho_\tau)\,p\epsilon_D - \epsilon_{D\tau}(1+\tau)}{(1+\tau\rho_\tau)\,p\epsilon_D}$$

□

Proof of Proposition 4

Proof. Note that

$$\frac{dp}{d\tau} = \frac{1}{1+\theta_\tau\tau}(mwtp(q)\frac{dq}{d\tau} - p\theta_\tau) \tag{A1}$$

The first order condition with J symmetric products and conduct parameter ν_q is $p - mc(q) = -\frac{\nu_q}{J}\frac{mwtp(q)q}{1+\theta_\tau\tau}$, substitute $p = \frac{wtp(q)-\theta_t t}{1+\theta_\tau\tau}$ so we get $\frac{wtp(q)-\theta_t t}{1+\theta_\tau\tau} - mc(q) = -\frac{\nu_q}{J}\frac{mwtp(q)q}{1+\theta_\tau\tau}$ or $wtp(q) - \theta_t t - mc(q)\,(1+\theta_\tau\tau) = -\frac{\nu_q}{J}mwtp(q)q$. Taking thederivative with respect to τ, we have

$$mwtp(q)\frac{dq}{d\tau} - (1+\theta_\tau\tau)\,mc'(q)\frac{dq}{d\tau} - mc(q)\theta_\tau = -\frac{\nu_q}{J}\left(mwtp'(q)\frac{dq}{d\tau}q + mwtp(q)\frac{dq}{d\tau}\right)$$

Rearrange terms, we have

$$\left((1+\frac{\nu_q}{J})mwtp(q) - (1+\theta_\tau\tau)\,mc'(q) + \frac{\nu_q}{J}mwtp'(q)q\right)\frac{dq}{d\tau} = mc(q)\theta_\tau$$

And so

$$\frac{dq}{d\tau} = \frac{mc(q)\theta_\tau}{(1+\frac{\nu_q}{J})mwtp(q) - (1+\theta_\tau\tau)\,mc'(q) + \frac{\nu_q}{J}mwtp'(q)q}$$
$$= \frac{\frac{mc(q)\theta_\tau}{mwtp(q)}}{(1+\frac{\nu_q}{J}) - \frac{mc'(q)q}{mc(q)}\frac{mc(q)(1+\theta_\tau\tau)}{mwtp(q)q} + \frac{\nu_q}{J}\frac{mwtp'(q)}{mwtp(q)}q}$$

Thus,

$$\frac{dq}{d\tau} = \frac{\theta_\tau\frac{mc(q)}{mwtp(q)}}{1 + \frac{(1+\theta_\tau)\epsilon_D^* - \frac{\nu_q}{J}}{\epsilon_S} + \frac{\frac{\nu_q}{J}}{\epsilon_{ms}}}$$

Therefore,

$$\frac{dp}{d\tau} = \frac{\theta_\tau}{1+\theta_\tau\tau}\left(\frac{\frac{mc(q)}{p}}{1 + \frac{(1+\theta_\tau)\epsilon_D^* - \frac{\nu_q}{J}}{\epsilon_S} + \frac{\frac{\nu_q}{J}}{\epsilon_{ms}}} - 1\right)$$

And

$$\rho_\tau = \frac{\theta_\tau(1+\tau)}{1+\theta_\tau\tau}\left(\frac{\frac{mc(q)}{p}}{1 + \frac{(1+\theta_\tau)\epsilon_D^* - \frac{\nu_q}{J}}{\epsilon_S} + \frac{\frac{\nu_q}{J}}{\epsilon_{ms}}} - 1\right) + 1$$

Similarly, we have

$$\frac{dp}{dt} = \frac{1}{1+\theta_\tau\tau}(mwtp(q)\frac{dq}{dt} - \theta_t)$$

The first order condition of monopoly is $p - mc(q) = -\frac{\nu_q}{J}\frac{mwtp(q)q}{1+\theta_\tau\tau}$, or $wtp(q) - \theta_t t - mc(q)\,(1+\theta_\tau\tau) = -\frac{\nu_q}{J}mwtp(q)q$. Taking the derivative w.r.t t we get:

$$\left(mwtp(q) - mc'(q)\,(1+\theta_\tau\tau) + \frac{\nu_q}{J}mwtp'(q)q + \frac{\nu_q}{J}mwtp(q)\right)\frac{dq}{dt} = \theta_t$$

And so

$$\frac{dq}{dt} = \frac{\theta_t}{mwtp(q) - mc'(q)\,(1+\theta_\tau\tau) + \frac{\nu_q}{J}mwtp'(q)q + \frac{\nu_q}{J}mwtp(q)}$$
$$= \frac{\frac{\theta_t}{mwtp(q)}}{1 - \frac{mc'(q)q}{mc(q)}\frac{(1+\theta_\tau\tau)mc(q)}{mwtp(q)q} + \frac{\frac{\nu_q}{J}\left(mwtp'(q)q + mwtp(q)\right)}{mwtp(q)}}$$

Thus,

$$\frac{dq}{dt} = \frac{\frac{\theta_t}{mwtp(q)}}{1 + \frac{(1+\theta_\tau)\epsilon_D^* - \frac{\nu q}{J}}{\epsilon_S} + \frac{\frac{\nu q}{J}}{\epsilon_{ms}}}$$

Therefore,

$$\frac{dp}{dt} = \frac{\theta_t}{1+\theta_\tau \tau}\left(\frac{1}{1 + \frac{(1+\theta_\tau)\epsilon_D^* - \frac{\nu q}{J}}{\epsilon_S} + \frac{\frac{\nu q}{J}}{\epsilon_{ms}}} - 1\right)$$

consumer price is

$$\rho_t = 1 + \frac{dp}{dt}(1+\tau) = 1 + \frac{(1+\tau)\theta_t}{1+\theta_\tau \tau}\left(\frac{1}{1 + \frac{(1+\theta_\tau)\epsilon_D^* - \frac{\nu q}{J}}{\epsilon_S} + \frac{\frac{\nu q}{J}}{\epsilon_{ms}}} - 1\right)$$

□

Proof of Proposition 5

Proof. Denote $wtp = p(1+\theta_\tau \tau) + \theta_t t$ the perceived price by the consumer and $\epsilon_D^* = \epsilon_D \frac{p}{p(1+\tau)+t}$. We have

$$\begin{aligned}\frac{dCS}{d\tau} &= wtp(Q)\frac{dQ}{d\tau} - Q\frac{d(p(1+\tau)+t)}{d\tau} - (p(1+\tau)+t)\frac{dQ}{d\tau} \\ &= -Q\frac{d(p(1+\tau)+t)}{d\tau} - \frac{dQ}{d\tau}\Big((1-\theta_\tau)p\tau + (1-\theta_t)t\Big)\end{aligned}$$

$$\begin{aligned}\frac{dCS}{dt} &= wtp(Q)\frac{dQ}{dt} - Q\frac{d(p(1+\tau)+t)}{dt} - (p(1+\tau)+t)\frac{dQ}{dt} \\ &= -Q\frac{d(p(1+\tau)+t)}{dt} - \frac{dQ}{dt}\Big((1-\theta_\tau)p\tau + (1-\theta_t)t\Big)\end{aligned}$$

$$\begin{aligned}\frac{dPS}{d\tau} &= \frac{d\Big((p - mc(q))q\Big)}{d\tau} \\ &= \frac{dp}{d\tau}q + \Big(p - mc(q)\Big)\frac{dq}{d\tau}\end{aligned}$$

$$\frac{dPS}{dt} = \frac{d\Big((p - mc(q))q\Big)}{dt}$$
$$= \frac{dp}{dt}q + \Big(p - mc(q)\Big)\frac{dq}{dt}$$

$$\frac{dR}{d\tau} = (\tau p + t)\frac{dQ}{d\tau} + Q\frac{d(\tau p + t)}{d\tau}$$
$$= (\tau p + t)\frac{dQ}{d\tau} - \frac{p\tau}{\epsilon_D}\frac{dQ}{d\tau} - (1+\tau)\frac{p}{\epsilon_D \rho_\tau}\frac{dQ}{d\tau}$$

$$\frac{dR}{dt} = (\tau p + t)\frac{dQ}{dt} + Q\frac{d(\tau p + t)}{dt}$$
$$= (\tau p + t)\frac{dQ}{dt} - \frac{p\tau}{\epsilon_D}\frac{dQ}{dt} - \frac{p}{\epsilon_D \rho_t}\frac{dQ}{d\tau}$$

Therefore, we have

$$\frac{dW}{d\tau} = \frac{dCS}{d\tau} + \frac{dPS}{d\tau} + \frac{dR}{d\tau}$$
$$= (p(1 + \theta_\tau \tau) + \theta_t t - mc(q))\,\frac{dQ}{d\tau}$$

$$\frac{dW}{dt} = (p(1 + \theta_\tau \tau) + \theta_t t - mc(q))\,\frac{dQ}{dt}$$

We also have

$$MC_\tau = -\frac{\frac{dW}{d\tau}}{\frac{dR}{d\tau}}$$
$$= -\frac{p(1 + \theta_\tau \tau) + \theta_t t - mc(q)}{(\tau p + t) - \frac{p\tau}{\epsilon_D} - (1+\tau)\frac{p}{\epsilon_D \rho_\tau}}$$
$$= \epsilon_D^* \frac{\frac{wtp - mc}{p}}{\frac{1 + \tau\rho_\tau}{(1+\theta_\tau \tau)\rho_\tau + \theta_\tau - 1} - \epsilon_D^*(\tau + \frac{t}{p})}$$

And

$$MC_t = -\frac{\frac{dW}{dt}}{\frac{dR}{dt}}$$
$$= -\frac{p(1+\theta_\tau\tau)+\theta_t t - mc(q)}{(\tau p + t) - \frac{p\tau}{\epsilon_D} - \frac{p}{\epsilon_D \rho_t}}$$
$$= \epsilon_D^* \frac{\frac{wtp - mc}{p}}{\frac{1+\tau\rho_\tau}{(1+\theta_\tau\tau)\rho_\tau + \theta_\tau - 1} - \epsilon_D^*(\tau + \frac{t}{p})}$$

□

Derivations for ad valorem tax with heterogeneous consumers (used in calibrations)

For reference, we add the formulas to calculate the effect of increasing an ad-valorem tax on consumer surplus, and producer surplus in the presence of heterogenous consumers. We also derive the marginal excess burden and incidence formulas that we take to the data. Recall $\rho_\tau \equiv \frac{1}{p}\frac{\partial(p(1+\tau)+t)}{\partial\tau}$ and $D(p,t,\tau) = D(p(1+\theta_\tau\tau)+\theta_t t, 0, 0)$. Then

$$\frac{dCS}{d\tau} = -pQ\rho_\tau - \frac{dQ}{d\tau}\left((1-\mathbb{E}(\theta_\tau))p\tau + (1-\mathbb{E}(\theta_t))t\right) + p\tau * Cov\left(\theta_{i\tau}, \frac{dQ_i}{dt}\right) + t * Cov\left(\theta_{it}, \frac{dQ_i}{dt}\right)$$

$$\frac{dPS}{d\tau} = -pQ * \left[\left(1-\frac{\nu_q}{J}\right)\left(\frac{1}{1+\tau}\right)[1-\rho_\tau] + \frac{\nu_q}{J} * \left(1 - \frac{\tau}{1+\tau}(1-\rho_\tau)\right)\left[\mathbb{E}(\theta_{i\tau}) + \frac{Cov\left(\theta_{i\tau}, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right]\right]$$

If only there is no unit tax, then $\theta_t = t = 0$ and so:

$$\frac{dCS}{d\tau} = -pQ\rho_\tau - \frac{dQ}{d\tau}\left((1-\mathbb{E}(\theta_\tau))p\tau\right) + p\tau * Cov\left(\theta_{i\tau}, \frac{dQ_i}{dt}\right)$$

$$\frac{dPS}{d\tau} = -pQ * \left[\left(1-\frac{\nu_q}{J}\right)\left(\frac{1}{1+\tau}\right)[1-\rho_\tau] + \frac{\nu_q}{J} * \left(1 - \frac{\tau}{1+\tau}(1-\rho_\tau)\right)\left[\mathbb{E}(\theta_{i\tau}) + \frac{Cov\left(\theta_{i\tau}, \frac{\partial Q_i}{\partial p}\right)}{\frac{\partial Q}{\partial p}}\right]\right]$$

Furthermore, under assumption 1:

$$\frac{dCS}{d\tau} = -pQ\rho_\tau - \frac{dQ}{d\tau}\left((1-\mathbb{E}(\theta_{i\tau}))p\tau\right) + p\tau * \frac{\partial Q}{\partial p} Var\left(\theta_{i\tau}\right)$$

$$\frac{dPS}{d\tau} = -pQ * \left[\left(1 - \frac{\nu_q}{J}\right)\left(\frac{1}{1+\tau}\right)[1-\rho_\tau] + \frac{\nu_q}{J} * \left(1 - \frac{\tau}{1+\tau}(1-\rho_\tau)\right)[\mathbb{E}(\theta_{i\tau})]\right]$$

From where, we can derive a formula for incidence:

$$I = \frac{\rho_\tau + (1-\mathbb{E}(\theta_{i\tau}))\frac{\tau}{Q}\frac{dQ}{d\tau} - \frac{\tau}{Q} * \frac{\partial Q}{\partial p} Var(\theta_{i\tau})}{\left(1 - \frac{\nu_q}{J}\right)\left(\frac{1}{1+\tau}\right)[1-\rho_\tau] + \frac{\nu_q}{J} * \left(1 - \frac{\tau}{1+\tau}(1-\rho_\tau)\right)\mathbb{E}(\theta_{i\tau})}$$

And so:

$$\frac{dW}{d\tau} = (p(1+\mathbb{E}(\theta_{i\tau})\tau) - mc(q))\frac{dQ}{d\tau} + p\tau * \frac{\partial Q}{\partial p} Var(\theta_{i\tau})$$

Finally, for the empirical implementation we use the follwing variations:

$$I = \frac{\rho_\tau + (1-\mathbb{E}(\theta_{i\tau}))\frac{\tau}{1+\tau}\frac{dlog(Q)}{dlog(1+\tau)} - \frac{\tau}{p} * \frac{\partial log(Q)}{\partial log(p)} Var(\theta_{i\tau})}{\left(1 - \frac{\nu_q}{J}\right)\left(\frac{1}{1+\tau}\right)[1-\rho_\tau] + \frac{\nu_q}{J} * \left(1 - \frac{\tau}{1+\tau}(1-\rho_\tau)\right)\mathbb{E}(\theta_{i\tau})}$$

$$\frac{dW}{d\tau}\frac{1+\tau}{Q} = (p(1+\mathbb{E}(\theta_{i\tau})\tau) - mc(q))\frac{dlog(Q)}{dlog(1+\tau)} + \tau(1+\tau) * \frac{\partial log(Q)}{\partial log(p)} Var(\theta_{i\tau})$$

Online Appendix Table OA.1: 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.

Online Appendix Table OA.2: 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/

Online Appendix Table OA.3:
OLS and Instrumental Variables Estimates of the Effects of Sales Taxes on Prices and Quantity

Sample:	County Border Pair Sample		County Border Pair Sample **[Instrumental Variables Estimates]**	
Dependent variable:	Price	Quantity	Price	Quantity
	(1)	(2)	(3)	(4)
$\log(1 + \tau_{mcs})$	0.986	-0.650	0.977	-0.594
	(0.016)	(0.084)	(0.017)	(0.093)
First-stage coefficient for $\log(1 + \tau_{ms})$			1.011	
			(0.002)	
First stage F-statistic			413,454	
Specification:				
Store × Module fixed effects	y	y	y	y
Module × Year-Quarter fixed effects	y	y	y	y
Module × State × Year-Quarter fixed effects	y	y		
Module × Border Pair × Year-Quarter fixed effects			y	y
N (observations)	33,749,157	33,749,157	33,749,157	33,749,157
N (modules)	198	198	198	198
N (stores)	2,714	2,714	2,714	2,714
N (counties)	468	468	468	468
N (county-modules)	88,249	88,249	88,249	88,249

Notes: Columns (1) and (2) replicate the estimates of the OLS effects of sales taxes on quantity and prices reported in Table 2, column (2) (Panel A and Panel B). In columns (3) and (4), we report 2SLS estimates from instrumenting the county-level module-specific sales tax rates with the associated state-level sales tax rate. The independent variable is quarterly sales tax rate of module m in county c in state s and the instrument is is quarterly sales tax rate of module m in state s. One observation is a module in a store in a given quarter. Consumer prices $p(1+\tau)$ are tax inclusive. The Retail Scanner data is restricted to modules above the 80th percentile of the national distribution of sales. The sample is restricted to stores in border counties. Observations are weighted by the inverse of the number of times a store appears in the data. The regression model includes module-by-store and module-by-year-quarter-by-pair fixed effects, where pairs denote pairs of contiguous counties.

Online Appendix Table OA.4: Reduced-form OLS Estimates of the Effects of Chain Instrument on Prices and Quantity

Sample:	Full Sample						County Border Pair Sample					
Dependent variable:	Price			Quantity			Price			Quantity		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Leave-me-out chain average log(*p*)	0.969			-1.165			0.964			-1.179		
	(0.002)			(0.026)			(0.003)			(0.026)		
Leave-county-out chain average log(*p*)		0.951			-1.148			0.951			-1.155	
		(0.003)			(0.026)			(0.003)			(0.026)	
Index based on UPC-level leave-me-out chain average log(p)			0.981			-1.062			0.975			-1.086
			(0.002)			(0.024)			(0.003)			(0.023)
Specification:												
Store × Module fixed effects	y	y	y	y	y	y	y	y	y	y	y	y
Module × Year-Quarter fixed effects	y	y	y	y	y	y	y	y	y	y	y	y
Module × State × Year-Quarter fixed effects	y	y	y	y	y	y						
Module × Border Pair × Year-Quarter fixed effects							y	y	y	y	y	y
N	53,895,446	53,890,260	53,892,855	53,895,446	53,890,260	53,892,855	33,749,157	33,739,222	33,746,705	33,749,157	33,739,222	33,746,705

Notes: This table reports estimates of the reduced-form effect of price instruments on consumer prices and quantity sold. One observation is a module in a store in a given quarter. Consumer prices are tax inclusive. The Retail Scanner data is restricted to modules above the 80th percentile of the national distribution of sales. All standard errors in this table are clustered at the state-module level and are reported in parentheses. In columns (1) to (6), the sample includes our full sample of stores and the regression model includes module-by-store and module-by-quarter-by-state fixed effects. In columns (7) to (12), the sample is restricted to stores in border counties. Observations are weighted by the inverse of the number of times a store appears in the data. The regression model includes module-by-store and module-by-quarter-by-pair fixed effects, where pairs denote pairs of contiguous counties. In columns (1), (4), (7) and (10) the independent variable is the chain average log price leaving store r out. In columns (2), (5), (8), and (11) the independent variable is the chain average log price leaving all stores in county c out. In remaining columns, the dependent variable is a regression-adjusted price index where each UPCs price is a leave-me-out chain average price.

Online Appendix Table OA.5: Robustness to Local Trends

Sample:	Full Sample		
	(1)	(2)	(3)
Panel A: Reduced-form OLS Estimates of the Effects of Sales Taxes on Consumer Prices and Quantity			
$d\log(p(1+\tau))/d\log(1+\tau)$	0.961	0.926	0.928
	(0.045)	(0.036)	(0.036)
$d\log(Q)/d\log(1+\tau)$	-0.668	-0.507	-0.336
	(0.185)	(0.165)	(0.164)
Panel B: 2SLS Estimates of the Price Elasticity of Demand			
$d\log(Q)/d\log(p)$	-1.202	-1.127	-1.064
	(0.027)	(0.030)	(0.030)
Panel C: "Plug-in" Estimate of the Tax Salience Parameter			
θ	0.575	0.507	0.376
Specification:			
Store × Module fixed effects	y	y	y
Module × Year-Quarter fixed effects	y	y	y
Module × State × Year-Quarter fixed effects	y		
Module × County × Linear time trend		y	
Module × Store × Linear time trend			y
N	53,895,446	53,902,268	53,902,268

Notes: This table reports estimates of the effects of sales taxes, of the price elasticity of demand, and of the tax salience parameter. In Panel A, the independent variable is quarterly sales tax rate of module m in county c in state s. One observation is a module in a store in a given quarter. Consumer prices $p(1+\tau)$ are tax inclusive. The Retail Scanner data is restricted to modules above the 80th percentile of the national distribution of sales. In Panel B, the reported coefficients are 2SLS estimates of the effect of consumer prices on quantity sold, where prices are instrumented with leave-self-out chain-level average prices. In Panel C, we report the estimate of the tax salience parameter. All standard errors in this table are clustered at the state-module level and are reported in parentheses. The sample includes our full sample of stores. In columns (1), the regression model includes module-by-store and module-by-quarter-by-state fixed effects. In column (2), the regression model includes module-by-store and module-by-quarter fixed effects, as well as county-module specific time trends. In column (3), the regression model includes module-by-store and module-by-quarter fixed effects, as well as store-module specific time trends.

Online Appendix Table OA.6: Reduced-form OLS Estimates of the Effects of Sales Taxes on Quantity and Expenditure

Sample:	Full Sample			County Border Pair Sample		
Dependent variable:	Quantity	Pre-tax price	Expenditure	Quantity	Pre-tax price	Expenditure
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Reduced-form OLS Estimates of the Effects of Sales Taxes						
$\log(1+\tau)_{mrn}$	-0.668	-0.0388	-0.741	-0.650	-0.014	-0.667
	(0.185)	(0.045)	(0.183)	(0.084)	(0.016)	(0.083)
Implied effect on quantity		-0.702			-0.653	
Panel B: Reduced-form OLS Estimates of the Effects of the Price Instrument						
z_{mrn}	-1.165	0.969	-0.351	-1.179	0.964	-0.359
	(0.026)	(0.002)	(0.0249)	(0.026)	(0.002)	(0.024)
Implied effect on quantity		-1.320			-1.323	
Panel C: "Plug-in" Estimate of the Tax Salience Parameter						
θ		0.552			0.491	
Specification:						
Store × Module fixed effects	y	y	y	y	y	y
Module × Year-Quarter fixed effects	y	y	y	y	y	y
Module × State × Year-Quarter fixed effects	y	y	y			
Module × Border Pair × Year-Quarter fixed effects				y	y	y
N (observations)	53,895,446	53,895,446	53,895,446	33,749,157	33,749,157	33,749,157
N (modules)	198	198	198	198	198	198
N (stores)	8,652	8,652	8,652	2,714	2,714	2,714
N (counties)	1,460	1,460	1,460	468	468	468
N (county-modules)	277,398	277,398	277,398	88,249	88,249	88,249

Notes: This table replicates the key parameters reported in Table 2, but using an alternative measure of quantity. Here, we report separately the effects of sales taxes (Panel A) and the effects of the price instrument (Panel B) on total expenditures on module m in store r at time n and on pre-tax prices. We then report the difference between the effect on expenditure and on prices as an alternative measure of the effect on quantity. Panel C reports the associated value of the tax salience parameter. The Retail Scanner data is restricted to modules above the 80th percentile of the national distribution of sales. All standard errors in this table are clustered at the state-module level and are reported in parentheses. In columns (1) to (3), the sample includes our full sample of stores and the regression model includes module-by-store and module-by-quarter-by-state fixed effects. In columns (4) to (6), the sample is restricted to stores in border counties. Observations are weighted by the inverse of the number of times a store appears in the data. The regression model includes module-by-store and module-by-quarter-by-pair fixed effects, where pairs denote pairs of contiguous counties.

Online Appendix Table OA.7: Calibration of Incidence and Marginal Excess Burden Formulas

[Table 3 Using County Border Pair Sample Estimates]

Tax salience parameter (θ):	Plug-in estimate of tax salience parameter, E[θ] = 0.528		Full salience, θ = 1	
Heterogeneity in θ:	(1/p)Var(θ) = 0	(1/p)Var(θ) = 0.25	No heterogeneity, (1/p)Var(θ) = 0	
Implied markup:	Baseline markup	Same markup from (1)	Same markup from (1)	Re-calibrate markup under θ = 1
	(1)	(2)	(3)	(4)
Panel A: Incidence and Marginal Excess Burden Formulas				
Incidence (I)				
General formula (imperfect salience, imperfect competition):	48.429	47.913	37.601	48.749
$(\rho_\tau(1+\tau) + (1-\theta)\tau\tilde{\varepsilon}_{D\tau} + \tau(1+\tau)\tilde{\varepsilon}_D(1/p)\text{Var}(\theta)) / ((1-v/J)(1-\rho_\tau) + (v/J)\theta(1+\tau\rho_\tau))$				
Incidence under perfect competition (for $0 < \theta \leq 1$)	∞	∞	∞	∞
Marginal Excess Burden ($d\tilde{W}/d\tau$)				
General formula (imperfect salience, imperfect competition):	-0.019	-0.029	-0.029	-0.026
$d\tilde{W}/d\tau = ((p-mc)/p + \theta\tau)\tilde{\varepsilon}_{D\tau} + \tau(1+\tau)\tilde{\varepsilon}_D(1/p)\text{Var}(\theta)$				
CLK / Taubinsky Rees-Jones formulas (perfect competition):	-0.012	-0.022	-0.022	
$d\tilde{W}/d\tau = \theta\tau\tilde{\varepsilon}_{D\tau} + \tau(1+\tau)\tilde{\varepsilon}_D(1/p)\text{Var}(\theta)$				
Panel B: Inputs and Intermediate Estimates Needed to Calibrate Formulas				
Inputs:				
Average tax rate, τ	0.034	0.034	0.034	0.034
Price Elasticity, $\tilde{\varepsilon}_D \equiv \partial\log(Q)/\partial\log(p)$	**-1.223**	**-1.223**	**-1.223**	**-1.223**
Tax Pass-Through, $\rho_\tau \equiv d\log(p(1+\tau))/d\log(1+\tau)$	**0.986**	**0.986**	**0.986**	**0.986**
Tax Elasticity, $\tilde{\varepsilon}_{D\tau} \equiv d\log(Q)/d\log(1+\tau)$	**-0.650**	**-0.650**	**-0.650**	**-0.650**
Tax Salience Parameter, θ				
Implied "Plug-In" Estimate of E[θ]	0.528	0.528		
Assuming full salience (E[θ] = 1)			1.00	1.00
(1/p)Var(θ)	0.00	0.25	0.00	0.00
Intermediate estimates:				
Implied estimate of $v/(J\epsilon_{ms})$	0.016	0.016		0.008
Implied markup $(p-mc)/p$	0.011	0.011		0.006
Implied estimate of v/J	0.013	0.013		0.007
(v/J = 0 is perfect competition, v/J = 1 is perfect collusion)				

Notes: This table reports calibrations of the tax incidence and marginal excess burden formulas. The results of these calibrations are shown in Panel A. Panel B presents the value of the input parameters taken from Table 2 column (2), as well as estimates of intermediate parameters. In column (1), the incidence and marginal excess burden formulas are implemented with no restrictions. In column (2) we allow for heterogeneity in salience parameter. In column (3), we use estimates of the markup based on the tax salience parameter reported in column (1), but assume full salience elsewhere in the formulas. In column (4), full salience is assumed throughout, including when calculating the markup.

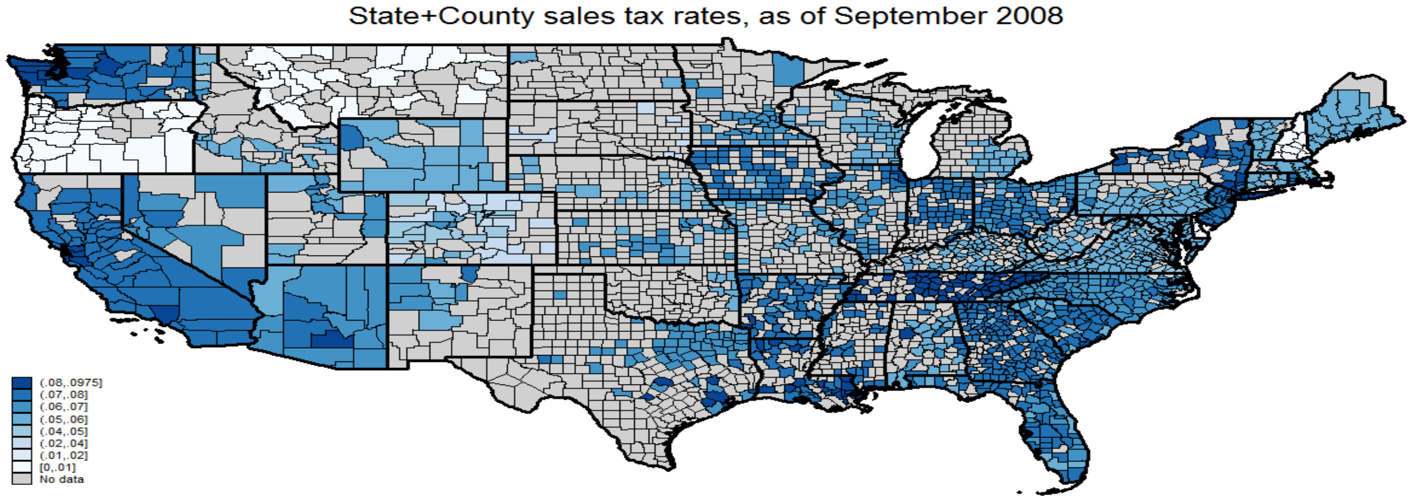
Online Appendix Table OA.8: Calibration of Incidence and Marginal Excess Burden Formulas

[Sensitivity of Table 3 to Alternative Values of Elasticity of Marginal Surplus]

Tax salience parameter (θ):	Plug-in estimate of tax salience parameter, E[θ] = 0.575				
Heterogeneity in θ:	(1/p)Var(θ) = 0				
Implied markup:	Baseline markup				
	(1)	(2)	(3)	(4)	(5)
Panel A: Incidence and Marginal Excess Burden Formulas					
Incidence (I)					
General formula (imperfect salience, imperfect competition):	17.051	19.489	18.129	16.473	15.932
$(\rho_\tau(1+\tau) + (1-\theta)\tau\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)\text{Var}(\theta)) / ((1-v/J)(1-\rho_\tau) + (v/J)\theta(1+\tau\rho_\tau))$					
Incidence under perfect competition (for $0 < \theta \leq 1$)	∞	∞	∞	∞	∞
Marginal Excess Burden ($d\tilde{W}/d\tau$)					
General formula (imperfect salience, imperfect competition):	-0.033	-0.025	-0.029	-0.035	-0.037
$d\tilde{W}/d\tau = ((p-mc)/p + \theta\tau)\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)\text{Var}(\theta)$					
CLK / Taubinsky Rees-Jones formulas (perfect competition):	-0.014	-0.014	-0.014	-0.014	-0.014
$d\tilde{W}/d\tau = \theta\tau\tilde{\epsilon}_{D\tau} + \tau(1+\tau)\tilde{\epsilon}_D(1/p)\text{Var}(\theta)$					
Panel B: Inputs and Intermediate Estimates Needed to Calibrate Formulas					
Inputs:					
Average tax rate, τ	0.036	0.036	0.036	0.036	0.036
Price Elasticity, $\tilde{\epsilon}_D \equiv \partial\log(Q)/\partial\log(p)$	-1.202	-1.202	-1.202	-1.202	-1.202
Tax Pass-Through, $\rho_\tau \equiv d\log(p(1+\tau))/d\log(1+\tau)$	0.961	0.961	0.961	0.961	0.961
Tax Elasticity, $\tilde{\epsilon}_{D\tau} \equiv d\log(Q)/d\log(1+\tau)$	-0.668	-0.668	-0.668	-0.668	-0.668
Tax Salience Parameter, θ					
Implied "Plug-In" Estimate of E[θ]	0.575	0.575	0.575	0.575	0.575
Assuming full salience (E[θ] = 1)					
(1/p)Var(θ)	0.00	0.00	0.00	0.00	0.00
Intermediate estimates:					
Implied estimate of $v/(J\epsilon_{ms})$	0.041	0.052	0.046	0.037	0.034
ϵ_{ms} (assume $1/\epsilon_D$ in col (1), sensitivity analysis in (2)-(5))	0.832	**0.400**	**0.600**	**1.000**	**1.200**
Implied markup $(p-mc)/p$, which equals $v/(J\epsilon_D)$	0.028	0.017	0.023	0.031	0.034
Implied estimate of v/J	0.034	0.021	0.028	0.037	0.041
(v/J = 0 is perfect competition, v/J = 1 is perfect collusion)					

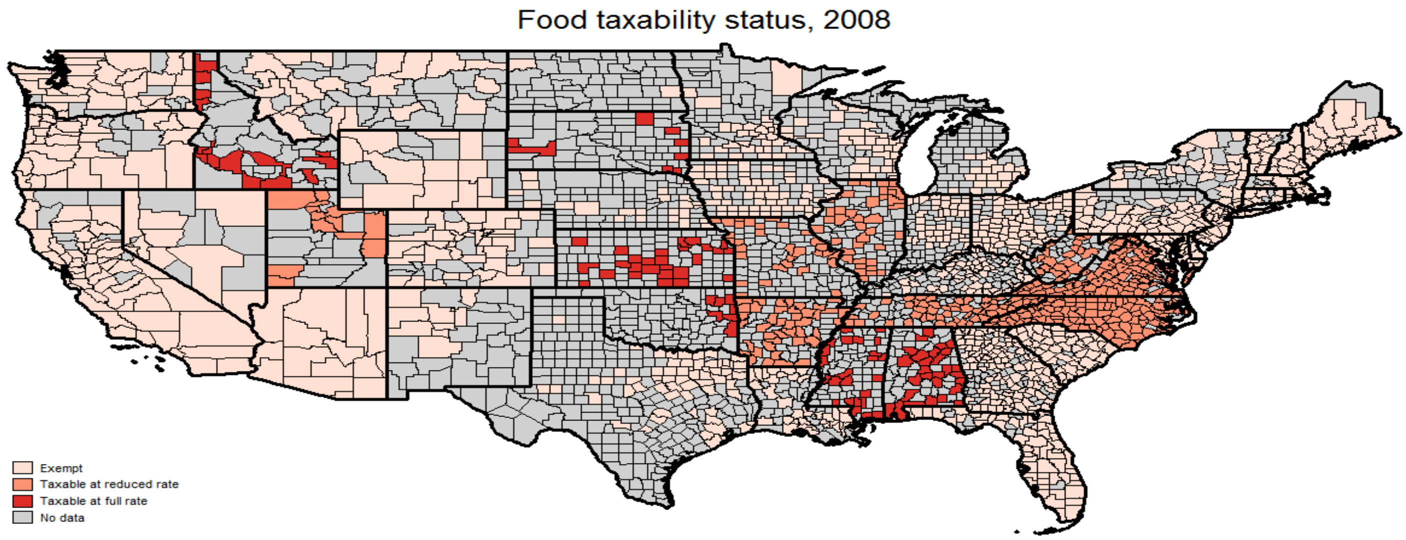
Notes: This table reports calibrations of the tax incidence and marginal excess burden formulas. The results of these calibrations are shown in Panel A. Panel B presents the value of the input parameters taken from Table 2 column (1), as well as estimates of intermediate parameters. In column (1), the calibration assumes a specific relationship between the demand elasticity and the elasticity of marginal surplus (ϵ_{ms}), while in the remaining columns the calibration assumes alternative values for ϵ_{ms}.

Online Appendix Figure OA.1: Map of Cross-Sectional Variation in Sales Tax Rates



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

Online Appendix Figure OA.2: Map of Cross-Sectional Variation in Sales Tax Exemption Status of Food Products



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