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Pass-through and tax incidence in differentiated product markets[☆]

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ABSTRACT

The role of demand curvature in determining firm behavior in symmetric oligopolistic product markets is well-understood. We consider the empirically relevant discrete choice differentiated product demand and point to two forces that drive curvature in logit demand: the impact of outside-good spending on the consumer's indirect utility and the heterogeneity in this response across consumers. We use the canonical example of the ready-to-eat cereal market (Nevo, 2000) to contrast elasticity and curvature estimates across several workhorse models. We illustrate that the log-concave Multinomial Logit and Nested Logit demands yield significantly biased curvature estimates. In contrast, a Mixed Logit specification generates a wider range of curvatures, including curvatures larger than one. These results are of immediate relevance to the robust assessment of tax incidence and the pass-through of cost savings, such as from a horizontal merger, in differentiated product markets.

1. Introduction

Since the works of Berry (1994) and Berry et al. (1995), the field of empirical industrial organization has relied heavily on the mixed logit framework to estimate the demand for differentiated products, most importantly because of its ability to accommodate unrestricted substitution patterns among numerous products.[1] A central empirical object of interest has been the demand elasticity. Key contributions aim to obtain reliable estimates of demand elasticities while accounting for income effects (Berry et al., 1995); ameliorating endogeneity problems through the inclusion of product fixed effects (Nevo, 2001); adding micro-moments (Petrin, 2002; Berry et al., 2004); improving the numerical methods used in estimation (Dubé et al., 2012); accounting for endogenous product positioning (Fan, 2013; Sweeting, 2013); and improving identification of the underlying demand parameters (Reynaert and Verboven, 2013; Gandhi and Houde, 2020).

Empirical studies of cost pass-through frequently embed a discrete choice model of demand in a model of Bertrand Nash pricing by oligopolistic firms.[2] While it is well-known that mixed logit is capable of approximating a wide array of substi-

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[1] The history of mixed logit dates back to Boyd and Mellman (1980) and Cardell and Dunbar (1980).

[2] Examples include Goldberg and Hellerstein (2007), Hellerstein and Villas-Boas (2010), Nakamura and Zerom (2010), Nakamura and Zerom (2010), Bonnet et al. (2013), and Fabra and Reguant (2014).

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tution patterns (McFadden and Train, 2000), little attention has been paid to the robust estimation of demand curvature in these models, however, despite a well established understanding of its role in determining the magnitude of cost pass-through in monopolistic markets (Cournot, 1838). Demand curvature plays a central role in governing the responsiveness of prices to changes in exchange rates (international trade); how "upward pricing pressure" (UPP) translates to a price increase after a cost-reducing merger (antitrust); and tax incidence (public finance). Our own recent work (Miravete et al., 2018) shows that demand curvature dictates whether the strategic price response to commodity taxation by firms with market power reinforces or partially unravels the government's ability to rely on commodity taxation as a source of tax revenue.

Weyl and Fabinger (2013) use the pass-through rate implied by demand curvature to characterize firm behavior in monopoly and homogeneous products symmetric and asymmetric oligopoly. Bulow and Pfleiderer (1983) show how preferences impose ex-ante constraints on the magnitude and sign of cost pass-through via demand curvature. In this paper, we similarly show that simple models of discrete choice, differentiated products demand (i.e.Multinomial Logit, Nested Logit) restrict cost pass-through and therefore have the potential to understate tax incidence and merger effects in oligopolistic settings, particularly when demand is log-convex.

Our results suggest that a mixed logit demand system not only imposes few restrictions on cost pass-through, but also allows for markets where some products feature log-concave demand while others are log-convex. Hence, the pass-through rate and tax incidence can vary dramatically among products – an important feature when firms cater to a variety of different consumer types and researchers are interested in issues of inequality. We illustrate the empirical relevance of these considerations in the canonical breakfast cereal market from Nevo (2000).

While we consider only aggregate implications of model specification for demand curvature here, we document the sources of curvature in mixed logit models of discrete choice demand and demonstrate how to estimate pass-through rates flexibly in follow-on work (Miravete et al., 2023). In particular we show how heterogeneity in price sensitivity among consumers tends to increase demand curvature thereby allowing the model to attain the pass-through rates greater than one (i.e."over-shifting") that have been observed in many empirical settings.[3] Meanwhile, heterogeneity in preferences for characteristics tends to reduce demand curvature as this horizontal differentiation increases firms' local isolation in product characteristic space.

Despite the appeal of the flexibility of the mixed logit demand, its adoption for policy work has been slow as the model is computationally demanding and identification is not straightforward.[4] Focus has instead been placed on developing approximation techniques that capture the primary economic trade-offs but come with a low computational expense. For example, Shapiro (1996) documents that price increases following a merger are positively correlated with the "value of diverted sales." Farrell and Shapiro (2010) later formalize this idea of upward pricing pressure; it is part of the 2010 United States Merger Guidelines. Jaffe and Weyl (2013) demonstrate theoretically that precise price effects can be obtained to a first-order approximation by scaling UPP with a pass-through matrix that captures the rate at which the merged entity transmits the change in its pricing incentives to the consumer. The evidence in Miller et al. (2017) illustrates, however, that the accuracy of UPP in estimating merger effects depends on the particular demand environment.

Similarly, while Jaffe and Weyl (2013) point to the value of pass-through information in improving the precision of predicted merger price effects, such data are frequently either not available or subject to measurement error.[5] As the computational burden of estimating flexible demand systems continues to fall, their ability to accommodate flexible curvature patterns as revealed by the data may thus enable not only improved prediction and inference in academic research, but also better informed public policy.

In the following section we present a simple single-product monopoly model of excise taxation. This model is useful as it provides a well-known setting to discuss firm market power and the role of curvature in pass-through and tax incidence. In Section 3 we document determinants of market power and demand curvature in discrete choice models of demand. We evaluate demand curvature restrictions empirically in Section 4 and conclude in Section 5.

2. A simple theoretical framework

We begin by presenting a simple model of monopoly taxation in order to illustrate the pricing and quantity response of firms with market power to changes in cost and taxation. Consider a single-product, constant-returns-to-scale monopolist with marginal cost c. We restrict attention to two tax instruments: a per-unit tax on producers, which shifts marginal cost c, and a per-unit tax t paid by the consumer. We allow for the case of $t < 0$ corresponding to a subsidy (e.g.electric cars). The final retail price p^r is thus a function of upstream taxation, which we include in the firm's marginal cost c, and downstream taxes; i.e.$p^r = p(c) + t$, where $p(c)$ denotes the price charged by the monopolist, which depends in turn on its cost, including any taxes levied on the firm.

[3] Examples include Poterba (1996), Besley and Rosen (1999) for grocery products, Young and Agnieszka (2002), Kenkel (2005) for alcohol, Besanko et al. (2005) for retail broadly, Marion and Muehlegger (2011) for gasoline, Pless and van Benthem (2019) for solar panels, and Miravete et al. (2022) for distilled spirits.

[4] See Berry and Haile (2014) for recent discussion regarding identification generally and Gandhi and Houde (2020) for identification of the random coefficients.

[5] The simulation evidence in Miller et al. (2016) highlights that inaccurate pass-through information feeds through to price effects estimated from the first-order approximation.

Let $q(p;t)$ denote the direct demand for the firm's product and $p(q;t)$ the corresponding inverse demand function. Both are positive, continuous, decreasing ($q_p(p;t) < 0$ and $p_q(q;t) < 0$), and three times differentiable. To maximize profits the monopolist equates marginal revenue and marginal cost so that demand is elastic in equilibrium:[6]

$$p(q;t) + q \cdot p_q(q;t) = p\left[1 - \frac{1}{\varepsilon(q)}\right] = c \quad \Longleftrightarrow \quad \varepsilon(q) \equiv -\frac{p(q;t)}{q \cdot p_q(q;t)} > 1\,. \tag{1}$$

Concavity of the profit function rules out excessively convex demands by requiring that at the equilibrium price, the monopolist's marginal revenue function is non-increasing:

$$2p_q(q;t) + q \cdot p_{qq}(q;t) = p_q(q;t)\big[2 - \rho(q;t)\big] < 0 \quad \Longleftrightarrow \quad \rho(q) \equiv -\frac{q \cdot p_{qq}(q;t)}{p_q(q;t)} < 2\,. \tag{2}$$

Writing elasticity ε and curvature ρ in terms of the firm's choice of price, we have:

$$\varepsilon(p) \equiv -\frac{p \cdot q_p(p;t)}{q(p;t)} > 1 \quad \text{and} \quad \rho(p) \equiv \frac{q(p;t) \cdot q_{pp}(p;t)}{\big[q_p(p;t)\big]^2} < 2\,. \tag{3}$$

The slope of demand plays a central role in the profit maximization necessary condition, which we rewrite in terms of the demand elasticity in Eq. (1); it determines the price markup (Lerner Index). The sufficient condition for profit maximization further restricts the slope of the marginal revenue function to be negative, which in turn we rewrite in Eq. (2) as a constraint on the equilibrium curvature of demand. Curvature drives both pass-through and the firm's response in the price p it collects to a change in the tax on the producer (c) or the consumer (t):

$$\frac{dp}{dc} = \frac{1}{2 - \rho(q)} \tag{4}$$

$$\frac{dp}{dt} = \frac{\rho(q) - 1}{2 - \rho(q)} \tag{5}$$

Demand can be concave ($\rho < 0$), linear ($\rho = 0$), or convex ($\rho > 0$). For $\rho < 1$, demand is log-concave and cost pass-through is incomplete (or under-shifted), while if $\rho > 1$, demand is log-convex and the pass-through rate exceeds 100% (i.e.over-shifted pass-through). Complete pass-through occurs when $\rho = 1$. This indeterminacy reflects the fact that the firm's demand $q(p;t)$ may be either log-supermodular or log-submodular in p and t.[7] The understanding of how demand curvature influences firm pass-through can be traced back to the seminal work of Cournot (1838) and more recent work by Bulow and Pfleiderer (1983) and Weyl and Fabinger (2013). Our focus is on the role of demand curvature in determining the magnitude and direction of the firm's response in logit models – the workhorse framework in empirical industrial organization.

Tax Incidence

Determining whether the burden of a tax falls on firms or consumers is a fundamental question within the field of public finance. Recall that in our setting with multiple taxation instruments, final retail price is a function of upstream taxation (firm costs) and downstream taxes; i.e.$p^r = p + t$. The equilibrium effect of a change in firm marginal cost c or the downstream tax t on the price paid by the consumer, p^r, is then

$$\frac{dp^r}{dc} = \frac{1}{2 - \rho(q)} \tag{6}$$

$$\frac{dp^r}{dt} = \frac{1}{2 - \rho(q)} \tag{7}$$

When the downstream market is regulated only via an excise tax or subsidy (i.e.$t \neq 0$), the magnitude of the retail price change is thus modulated only by the demand curvature. Equations (6) and (7) also illustrate the foundational result in public finance (Gruber, 2015) that the tax incidence between firms and consumers is invariant to where the tax is imposed – as a cost to the firm or a tax levied on the consumer.[8]

[6] It is straightforward to write the equivalent first-order condition for an oligopoly. The incidence of inelastic demands at observed equilibrium prices has become a common specification test in empirical demand estimation.

[7] See Topkis (1998) for a formal definition. Applications of log-supermodularity include auction theory (Milgrom and Weber, 1982); international trade (Costinot, 2009); monotone comparative statics (Milgrom and Shannon, 1994); its preservation under uncertainty (Jewitt, 1987); and in multivariate environments (Athey, 2002).

[8] In Miravete et al. (2022) we show the presence of a downstream ad-valorem tax negates this result; i.e.who bears the per-unit excise tax matters for tax incidence and the final equilibrium retail prices and quantities. Such ad-valorem taxes are commonly levied by local governments as sales taxes across a wide spectrum of goods. This theoretical result suggests that taxes that are levied on upstream manufacturers have larger impacts on final retail prices than previously thought.

Competition, Mergers and Antitrust

The curvature of demand also plays a central role in the analysis of horizontal mergers.[9] Consider an extension of the above model to two firms producing a differentiated product at constant marginal cost. Nash equilibrium satisfies the following set of first-order conditions in terms of each firm's choice of price:

$$p^i = -q^i(p)\left[q^i_{p_i}(p)\right]^{-1} + c^i \quad i = \{1,2\}, j = -i$$
$$p^i(p^j) = \frac{1}{1+1/\varepsilon_i(p)}c^j$$

where superscripts denote product identity $i = 1, 2$. Deriving cost pass-through now requires accounting for the strategic pricing best response of the other firm. Genakos and Pagliero (2022) provide quasi-experimental evidence that market structure indeed affects pass-through for a homogeneous goods industry (retail gasoline), though their analysis does not allow separating the contributions of market structure and curvature to cost pass-through.[10] The extent to which the competitive effects will dominate the role of demand curvature in determining pass-through is an open question that we leave for future research.

Suppose these firms merge and continue to offer both products at their original costs. The new prices satisfy the following set of first-order conditions:

$$p^i = -q^i(p)\left[q^i_{p_i}(p)\right]^{-1} + c^i - (p^j - c^j)q^j_{p_i}(p)\left[q^i_{p_i}(p)\right]^{-1} \quad i = \{1,2\}, j = -i \tag{8}$$
$$p^i(p^j) = \frac{1}{1+1/\varepsilon_i(p)}\left[c^i + \underbrace{(p^j - c^j)D_{ij}(p)}_{\text{Opportunity Cost}}\right]$$

where we have re-arranged the cross-price effects such that they amount to what the antitrust literature refers to as the "opportunity cost of foregone profits."[11] Equation (8) illustrates that in contrast to a single-product firm that prices according to the inverse elasticity rule, the merged multi-product entity chooses the price on a given product i based on both the product's demand elasticity and the diversion of product j's sales as product i's price changes scaled by product j's margin, or UPP. Jaffe and Weyl (2013) show that to a first-order approximation, the post-merger equilibrium prices that solve the set of necessary conditions (8) are equal to a merger pass-through matrix that captures the extent to which firms pass this opportunity cost on to prices scaled by UPP. The merger pass-through matrix, in turn, is a function of the first and second derivatives of demand; hence demand curvature will play a role in determining the price effects resulting from the merger.

Discussion

The above analysis demonstrates that changes in retail prices resulting from a change in government taxation or in firm costs depend fundamentally upon the degree of demand curvature, which may vary across competing products. Beyond overall impacts on price levels, taxation or mergers may therefore have distributional effects across demographic groups and firms. Hence, a first-order concern for any analysis of pass-through should be the estimation of such effects in an environment that places minimal restrictions on demand curvature – either in aggregate or across products. Yet, many demand systems impose such constraints ex-ante, such as $\rho(q) = 0$ and $\rho(q) = 1$ in linear and log-linear direct demands, respectively, or the relationship $\rho = (\varepsilon + 1)/\varepsilon$, where ε corresponds to the demand elasticity of iso-elastic Dixit-Stiglitz CES demand, and thus $\rho > 1$.[12] In these cases, much, if not all, of the strategic behavior of firms is pre-determined by the researcher via the empirical framework. In the remaining sections we consider the curvature properties of alternative variants of logit demand.

3. Elasticity and curvature in discrete choice models of demand

In this section we explore the relationship between curvature and elasticity in the specific case of discrete-choice demand models – the workhorse framework of empirical work in Industrial Organization. We provide a brief summary of our formulation in Miravete et al. (2023), demonstrating in particular, that the range of demand curvatures attainable at a given demand elasticity depends upon functional form assumptions of the "price-response subfunction," including the degree of heterogeneity among consumers in their sensitivity to price. Define the indirect utility of consumer i purchasing product j as:

$$u_{ij} = x_j\beta_i^\star + f_i(y_i, p_j) + \xi_j + \epsilon_{ij}, \qquad i \in \mathcal{I},\ j \in \mathcal{J},\ \epsilon_{ij} \sim \text{EV1}, \tag{9}$$

[9] Again, Cournot (1838) is the seminal work as he demonstrated that two monopolists were better-off merging in order to coordinate production decisions.

[10] Market structure also affects equilibrium prices which in turn influence demand curvature so it could be the case that demand curvature estimates play the dominant role in constant marginal cost environments.

[11] When goods are substitutes – as they are in many empirical applications – an increase in the price of product one drives an increase in quantity demanded for product two. The profit-maximizing firm therefore increases the price of good two and we have that the cross-price derivative $q^2_{p_1} < 0$ so a merger amounts to an increase in the firm's costs.

[12] As Cobb-Douglas amounts to a special case of CES preferences where $\varepsilon = 1$, curvature in this special case is equal to two.

where (x_j, ξ_j) denote observed and unobserved characteristics of product j, respectively, p_j its price, and y_i consumer i's income. We follow the literature in specifying heterogeneity in the valuation of product characteristic x by decomposing $\beta_i^\star$ into $\beta_i^\star = \beta + \sigma_x \nu_i$, where β denotes the mean valuation while ν_i captures the idiosyncratic heterogeneity in the valuation of the observed product characteristic, as captured by a standard normal random variable scaled by σ_x.

The subfunction f_i represents how spending on the outside good, $y_i - p_j$, affects indirect utility, i.e.for the quasi-linear preferences of Nevo (2000), $f_i(y_i, p_j) = \alpha_i(y_i - p_j)$. The effect of outside good spending varies by individual i, both because income varies across consumers and because consumers may differ in their price sensitivities, a point we focus on below. Without loss of generality, we normalize the characteristics and price of the outside alternative to zero.

Individual i purchases product j if $u_{ij} \geq u_{ik}, \ \forall k \in \{0, 1, \ldots, J\}$. Because of the additive i.i.d. type-I extreme value distribution of ϵ_{ij}, individual i's choice probability of product j is:

$$\mathbb{P}_{ij}(p) = \frac{\exp\left(x_j\beta_i^\star + f_i(y_i, p_j) + \xi_j\right)}{1 + \sum\limits_{k=1}^{J} \exp\left(x_k\beta_i^\star + f_i(y_i, p_k) + \xi_k\right)}. \tag{10}$$

Aggregating over the measure of heterogeneous individuals summarized by $G(i)$, total demand for product j is:

$$Q_j(p) = \int\limits_{i\in\mathcal{I}} \mathbb{P}_{ij}(p)\, dG(i). \tag{11}$$

We can now write elasticity and curvature of product j using the preferences defined by Eq. (9). To simplify notation we write:

$$f'_{ij} = \frac{\partial f_i(y_i, p_j)}{\partial p_j}, \qquad \text{and} \qquad f''_{ij} = \frac{\partial^2 f_i(y_i, p_j)}{\partial p_j^2}. \tag{12}$$

Thus, f'_{ij} represents the marginal effect of price p_j on consumer i's indirect utility while f''_{ij} represents how this marginal effect changes with price.

Logit demand implies a well-known own-price demand elasticity of product j of:

$$\varepsilon_j(p) = -\frac{p_j}{Q_j(p)} \int\limits_{i\in\mathcal{I}} f'_{ij} \cdot \mathbb{P}_{ij}(1 - \mathbb{P}_{ij})\, dG(i), \tag{13}$$

which amounts to a scale-free measure that aggregates weighted individual price responses (demand slopes). Similarly, the demand curvature of the logit discrete choice model is:

$$\rho_j(p) = \int\limits_{i\in\mathcal{I}} \mathbb{P}_{ij}\, dG(i) \times \frac{\int f''_{ij} \cdot \mathbb{P}_{ij}(1 - \mathbb{P}_{ij})\, dG(i) + \int \left(f'_{ij}\right)^2 \cdot \mathbb{P}_{ij}(1 - \mathbb{P}_{ij})(1 - 2\mathbb{P}_{ij}) dG(i)}{\left[\int f'_{ij} \cdot \mathbb{P}_{ij}(1 - \mathbb{P}_{ij}) dG(i)\right]^2}. \tag{14}$$

From Eqs. (13) and (14), we see that how the researcher defines the price-response subfunction $f(\cdot)$ plays a fundamental role in determining both demand elasticity (ε) and demand curvature (ρ). For example, for the case of the quasi-linear preferences above, when $f_{ij}(y_i, p_j) = \alpha_i(y_i - p_j)$, Eq. (14) suggests that the assumptions placed on the idiosyncratic price sensitivity α_i drive curvature.

When the subfunction is non-linear, curvature depends on the second derivative of the price-response subfunction as well. Examples include $f_{ij}(y_i, p_j) = \alpha \log(y_i - p_j)$ as used in Berry et al. (1995) and $f_{ij}(y_i, p_j) = \frac{p_j^\lambda - 1}{\lambda}$ in Birchall and Verboven (2022). The former specification includes income effects while the latter does not. In Miravete et al. (2023) we show that estimates of demand elasticity and curvature are sensitive to the modeling of this nonlinearity. In that paper we propose modeling the price-response subfunction as a flexible Box-Cox transformation of outside good spending, which allows the data to determine these features of demand by extending the set of feasible elasticity-curvature pairs.

Discussion

Section 2 illustrated that own- and cross-price elasticities of demand underlie estimates of market power, while curvature of demand plays an important role in the strategic pricing responses of firms to changes in cost and taxation, and hence pass-through. As Eqs. (13) and (14) illustrate, two models estimated on the same data and yielding the same elasticity estimates may imply different estimates for demand curvature, depending on the specific price-response subfunctions. Our focus in this paper is to address the implications of model specification bias in choosing the price-response subfunction by restricting demand to be log-concave ex ante.

4. An empirical example

To illustrate the elasticity and curvature properties of common logit demand specifications, we use the well-known simulated aggregate data for breakfast cereals (Nevo, 2000).[13] Categories such as consumer packaged goods like ready-to-eat cereal, where the consumer's expenditure on the product(s) amounts to a small share of their budget, are good examples where abstracting from wealth effects and relying on quasi-linear utility is appropriate. Following Nevo (2000), we thus consider the following empirical version of the indirect utility of consumer i in market t for product j in Eq. (9):

$$u_{ijt} = x_{jt}\beta_i^\star + \alpha_i^\star p_{jt} + \xi_{jt} + \epsilon_{ijt}, \qquad i \in \mathcal{I},\ j \in \mathcal{J}_t,\ t \in \mathcal{T},\ \epsilon_{ijt} \sim \text{EV1}, \tag{15a}$$

$$\begin{pmatrix} \alpha_i^\star \\ \beta_i^\star \end{pmatrix} = \begin{pmatrix} \alpha \\ \beta \end{pmatrix} + \Pi D_{it} + \Sigma \nu_{it}, \qquad \nu_i \sim N(0, I_{n+1}), \tag{15b}$$

where x_{jt} is the $(n \times 1)$ vector of observed product characteristics and p_{jt} is the price of (inside) product j available in each market, $\mathcal{J}$, with $J = |\mathcal{J}|$. Payoff of the outside good is $u_{i0} = \epsilon_{i0}$. We allow for the possibility of idiosyncratic preference heterogeneity in the valuation of product characteristics, β_i^* and price responsiveness, α_i^*. Preferences might be correlated to a d-vector of demographic traits D_{it} through the $(n+1) \times d$ matrix Π of interaction estimates that allows for cross-price elasticity to vary across markets with different demographic composition. ν_{it} and ϵ_{ijt} capture, as above, mean-zero, unobserved preference shifters with a diagonal variance-covariance matrix Σ and the i.i.d. Type-I extreme value idiosyncratic unobserved preference by consumer i for product j.

We consider four possible demand specifications and estimate each using the original set of Hausman-style price instruments from Nevo (2000). Model A is the specification used in Nevo (2000), which allows for normally distributed random coefficients on product attributes and prices. In Model B we allow for heterogeneity in $\alpha_{i\star}$ and $\beta_i^\star$ based on observable demographics only. In Model C, we eliminate all heterogeneity in price sensitivity $\alpha_{i\star}$ and we include only a random coefficient for product characteristics. We refer to this model as "pseudo nested logit" since the random coefficients connect substitution patterns with observable (to the econometrician) characteristics much as allowing correlations within the ϵ_{ijt} extreme value errors generates greater substitution within observable groups in a standard nested logit framework (Cardell, 1991;Berry, 1994).[14] Lastly, Model D amounts to a simple multinomial logit specification where we eliminate all random coefficients (Σ) and demographic interactions (Π). The four models can be characterized as follows:

A: Mixed Logit
$$\alpha_i^\star = \alpha + \textstyle\sum_{k=1}^{d} \pi_{\alpha k} D_{it} + \sigma_\alpha \nu_{it}, \quad \beta_i^\star = \beta + \sum_{k=1}^{d} \pi_k D_{it} + \sigma_k \nu_{it}, \tag{16a}$$

B: Demographics
$$\alpha_i^\star = \alpha + \textstyle\sum_{k=1}^{d} \pi_{\alpha k} D_{it}, \quad \beta_i^\star = \beta + \sum_{k=1}^{d} \pi_k D_{it}, \tag{16b}$$

C: Pseudo Nested Logit
$$\alpha_i^\star = \alpha, \quad \beta_i^\star = \beta + \sigma_k \nu_{it}, \tag{16c}$$

D: Multinomial Logit
$$\alpha_i^\star = \alpha, \quad \beta_i^\star = \beta, \tag{16d}$$

McFadden and Train (2000) demonstrate that the mixed logit framework is sufficiently flexible to represent any random utility model and therefore can account for a wide variety of empirically-relevant substitution patterns. While the mixed logit framework is flexible, it is data-intensive and computationally burdensome. Multinomial logit is often employed as a useful benchmark capable of generating reasonable results quickly, even though it constrains cross-price elasticities and diversion ratios. The nested logit specification is a hybrid that antitrust authorities often rely on; we include a variant of it here to assess its value as a compromise for estimating pass-through and tax incidence.

4.1. Estimation results

We display a subset of the estimated coefficients in Table 1, focusing on the coefficients that impact price sensitivity.[15] We further present the estimated own-price elasticity ε and curvature ρ pairs for each model in Fig. 1. While we observe that under any specification estimates are consistent with profit maximization (elastic demands) and a quasi-concave profit function (decreasing marginal revenue, $\rho < 2$), we observe stark differences in the distribution of estimated own-price elasticity and own-curvature pairs across the models.

[13] Breakfast cereal is an ideal application for the estimation of equilibrium models of horizontally differentiated products: firms have market power and set prices strategically as they offer a portfolio of products located across a large attribute space defined by calories per serving, sugar, fiber and other quality dimensions.

[14] While this model is not precisely a nested logit specification, McFadden and Train (2000) demonstrated that a mixed logit specification can generate equivalent substitution patterns to the nested logit model. In our setting, this model specification serves as a useful benchmark to evaluate the consequences of using models akin to the nested logit in terms of feasible elasticity-curvature pairs. We choose this particular formulation as it results directly from parameter restrictions on Model A.

[15] In Table 1, we report mean value estimates calculated via second-stage minimum distance estimation of brand fixed effects projected onto product characteristics as detailed in Nevo (2001).

Table 1
Breakfast Cereal Demand Estimates.

Parameter		Model Specification: Mixed Logit	Nested Logit	Demographics	MNL
Means	Constant	−2.0099	−2.9497	−1.9864	−2.9426
		(0.327)	(0.0891)	(0.2813)	−0.0878
	Price	−62.7299	−30.2228	−41.5297	−30.0978
		(14.8032)	(1.0423)	(7.5476)	−1.0332
	Sugar	0.1163	0.0458	0.1066	0.0448
		(0.016)	(0.0038)	(0.013)	−0.0034
	Mushy	0.4994	0.2565	0.3626	0.1086
		(0.1986)	(0.0543)	(0.1718)	−0.0404
Standard Deviations	Constant	0.5581	−0.1336		
		(0.1625)	(0.1529)		
	Price	3.3125			
		(1.3402)			
	Sugar	−0.0058	−0.0077		
		(0.0135)	(0.0159)		
	Mushy	0.0934	−0.2075		
		(0.1854)	(0.2855)		
Inter-actions	log(Income)-x-Constant	2.2920		2.0866	
		(2.292)		(0.9174)	
	log(Income)-x-Price	588.3252		204.6269	
		(588.3252)		(143.4835)	
	log(Income)-x-Sugar	−0.3850		−0.2313	
		(−0.385)		(0.0596)	
	log(Income)-x-Mushy	0.7484		1.0717	
		(0.7484)		(0.5285)	
	log(Income)^2-x-Price	−30.1920		−10.3392	
		(14.1012)		(7.4337)	
	Age-x-Constant	−30.1920		1.2356	
		(14.1012)		(0.672)	
	Age-x-Sugar	0.0522		0.0226	
		(0.026)		(0.0252)	
	Age-x-Mushy	−1.3534		−1.3868	
		(0.6671)		(0.7694)	
	Child-x-Price	11.0546		10.6906	
		(4.1226)		(4.0885)	
Statistics	Elasticity (ε)	3.6233	3.7267	3.6664	3.7126
		(0.9425)	(0.8786)	(0.8980)	(0.8749)
	Curvature (ρ)	1.0573	0.9786	1.0014	0.979
		(0.0832)	(0.0322)	(0.0597)	(0.0319)

Notes. GMM estimates of parameters related to price sensitivity using simulated breakfast cereal data. “Nested Logit” refers to the model we refer to as “pseudo nested logit” in the main text. Robust standard errors located in parentheses.

The estimated mixed logit model delivers a wide variety of elasticity and curvature combinations. In Miravete et al. (2023) we demonstrate that mixed logit can accommodate both log-concave and log-convex demands and that allowing for heterogeneity in price sensitivities enables the model to achieve demand curvatures greater than one, while allowing for heterogeneous tastes over characteristics reduces demand curvature (Fig. 2). Here, we see this result as panels (a) and (b) present similar elasticity-curvature pairs. Products where demand is largely explained through observable product characteristics for which consumers have heterogeneous tastes (e.g.sugar content) therefore tend to have lower estimated demand curvature. Products for which demand cannot be explained via heterogeneous tastes over observable product characteristics tend to have greater demand curvature reflecting the heterogeneous price-sensitivities among consumers. In the nested logit and multinomial logit models there is no scope for heterogeneous price sensitivities so demand curvature is truncated at one. This reflects that, while these models do not impose a specific curvature value ex ante, as the CES-demand does, they generate log-concave demand and therefore under-shifted pass-through. These results also document that while heterogeneous tastes for characteristics are important for delivering realistic substitution patterns, they are only one component in delivering flexible patterns for pass-through.

Lastly, we observe that the different specifications deliver little variation in the average elasticity – a statistic often reported by researchers in the literature to communicate that their results are reasonable – but that this aggregate statistic fails to communicate restrictions the model places on the distribution of either elasticity or curvature. It is hence of limited use in assessing the realism of the estimated pass-through estimates across products, a point that is particularly relevant when inequality is of concern. Instead, we encourage researchers to plot estimated elasticity-curvature pairs as in Fig. 1 to enable the reader to assess potential distributional consequences implied by the estimated demand system.

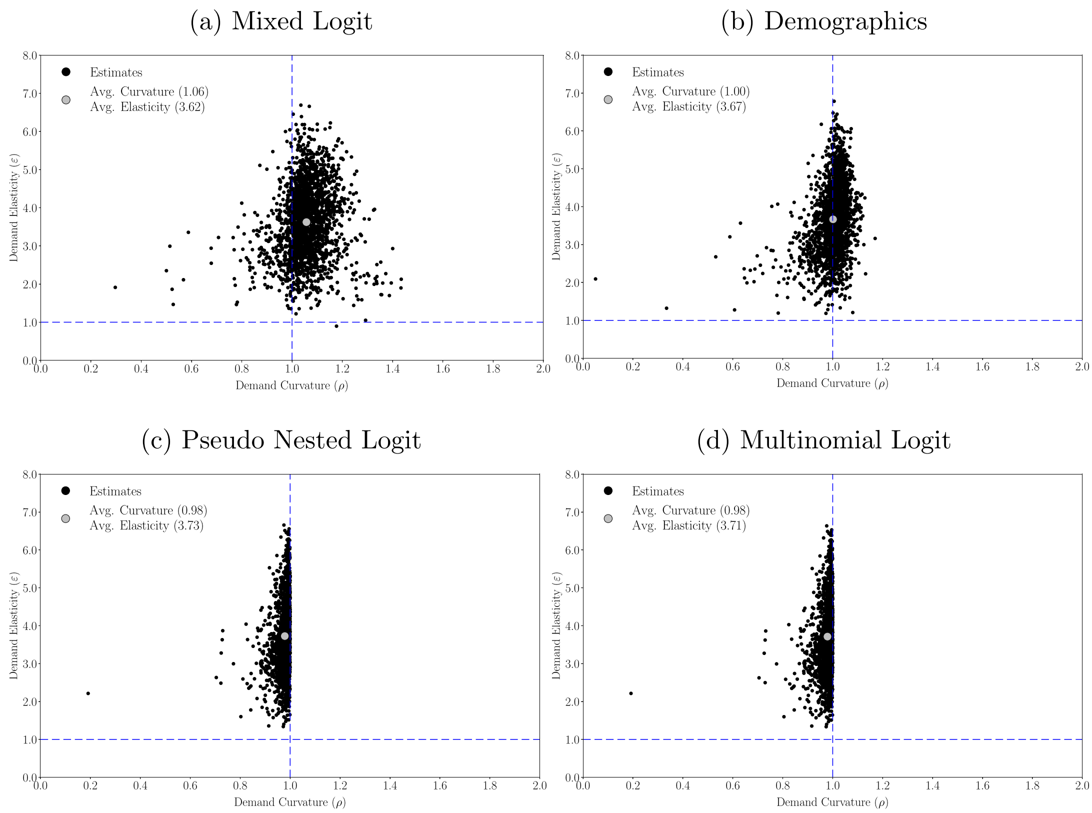

Figure Notes: Dots represent the estimated own-price elasticity and curvature for a product in the sample with the gray dot corresponding to the average elasticity and curvature.

Fig. 1. Breakfast Cereal: Elasticity and Curvature Estimates. Figure Notes: Dots represent the estimated own-price elasticity and curvature for a product in the sample with the gray dot corresponding to the average elasticity and curvature.

4.2. Estimates of market power and pass-through

We use the demand estimates to evaluate the implications of model specification on estimates of market power and tax incidence. For each estimated demand model, we recover estimated marginal costs via a standard model of static oligopoly pricing where F firms compete in prices and each firm $f \in F$ produces a subset J_t^f of the $j = 1, \ldots, J_t$ products. We assume that in each period t, firms set the vector of prices $\{p_{jt}\}_{j \in J_t^f}$ non-cooperatively as in a Bertrand-Nash differentiated products oligopoly to maximize period t profit

$$\max_{p_{jt}} \sum_{j \in J^f} \left[(p_{jt} - c_{jt}) \times M_t s_{jt} \Big(p(, x, \xi; \theta \Big) \right], \tag{17}$$

where c_{jt} denotes the marginal cost of product j in market t, s_{jt} the market share of product j in market t under the assumed demand specification (see, e.g. Nevo, 2000, for a derivation), and M_t is potential market size of t. To simplify the notation of this static problem, we omit the period t subscripts going forward. Profit maximization in the upstream market implies the following first-order condition for firm f's product j, $\forall j \in J^f$:

$$s_j \Big(p, x, \xi; \theta \Big) + \sum_{m \in J^f} \Big(p_m - c_m \Big) \times \frac{\partial s_m}{\partial p_j} = 0\,. \tag{18}$$

The final term $\frac{\partial s_m}{\partial p_j}$ is the response in product m's market share to a change in the price of product j. Assuming a pure-strategy equilibrium in prices, the vector of profit-maximizing prices is

$$p = c - \underbrace{[O * \Delta]^{-1} \times s\Big(p, x, \xi; \theta \Big)}_{\text{vector of \$ markups}}, \tag{19}$$

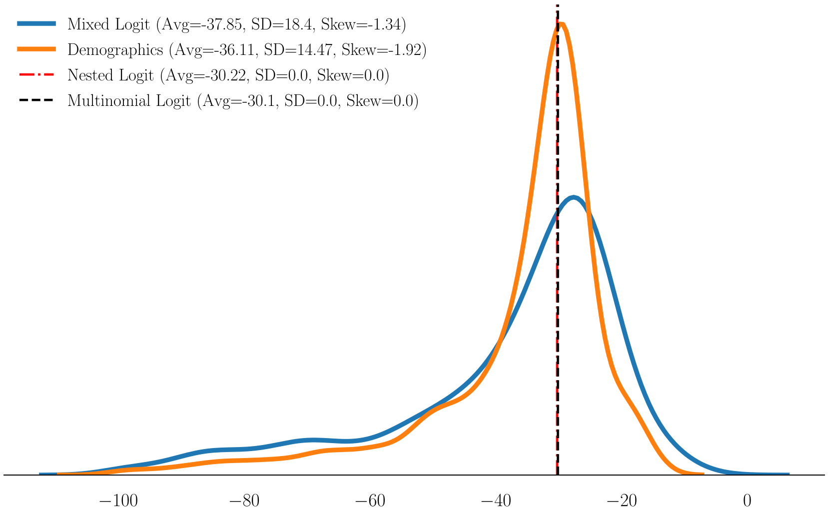

Fig. 2. Estimates of Heterogeneous Price Sensitivity ($\hat{\alpha}_i$).

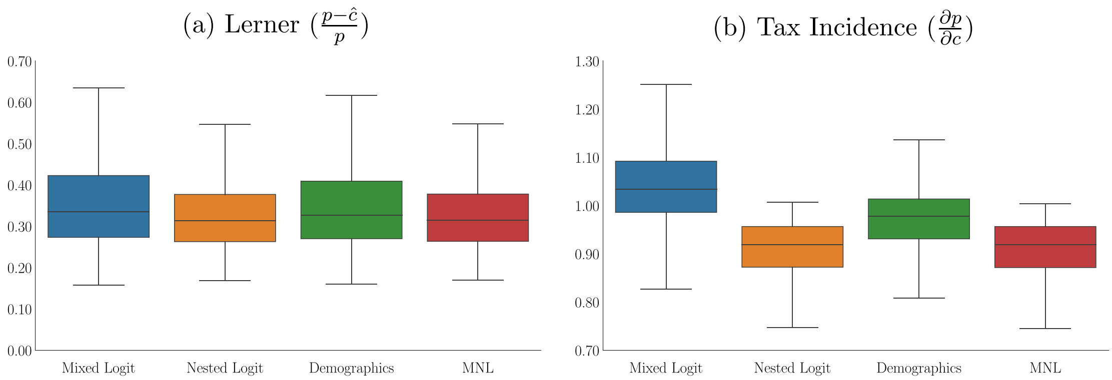

Figure Notes: Box plots display the distribution for estimated Lerner indices and pass-through rates across different demand specifications.

Fig. 3. Estimates of Market Power and Pass-Through. Figure Notes: Box plots display the distribution for estimated Lerner indices and pass-through rates across different demand specifications.

where O denotes the observed firm ownership matrix with element (j, m) equal to one if goods j and m are in J^f and firm f chooses these prices jointly. We define Δ as a matrix that captures changes in demand due to changes in price,

$$\Delta = -\begin{bmatrix} \frac{\partial s_1}{\partial p_1} & \cdots & \frac{\partial s_1}{\partial p_J} \\ \vdots & \ddots & \vdots \\ \frac{\partial s_J}{\partial p_1} & \cdots & \frac{\partial s_J}{\partial p_J} \end{bmatrix} \tag{20}$$

Equation (19) provides the theoretical foundation to recover estimated marginal costs given the estimated model of consumer demand alongside price data and firm ownership portfolios.

In Fig. 3 we present the our estimates of market power and tax incidence (pass-through). In Panel (a) we present the implied Lerner indices defined as estimated dollar markups ($p_j - \hat{c}_j$) relative to observed price (p_j). For all four models we observe similar estimates of market power (Lerner indices) which indicates similar magnitudes of own- and cross-price elasticities, though of course the substitution patterns across models vary significantly. This suggests that all of these models are sufficient for research questions that focus on estimates of market power and do not require computing new pricing equilibria.

In Panel (b) we present the estimated pass-through of a 10% increase in marginal costs. Note that this approach differs conceptually from the theoretical definition of pass-through in our simple single-product monopoly case in Section 2 as we allow for both multi-product firms and competition – forces that are empirically-relevant and may complicate the relationship between estimated demand curvature (Fig. 1) and predicted pass-through (Fig. 3).

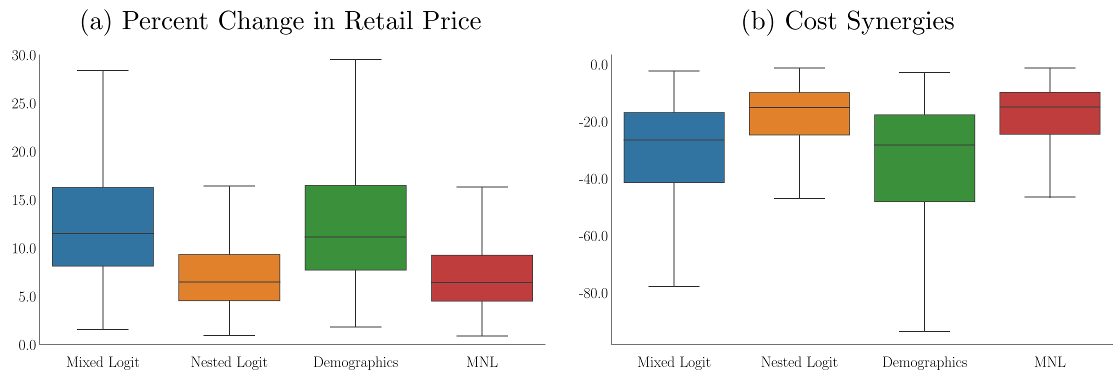

Figure Notes: Left panel represents the distribution of retail price changes owned by the two firms engaged in the merger. Right panel reflects the required cost synergies among the merging parties to keep prices unchanged.

Fig. 4. Merger Simulations. Figure Notes: Left panel represents the distribution of retail price changes owned by the two firms engaged in the merger. Right panel reflects the required cost synergies among the merging parties to keep prices unchanged.

Our results demonstrate that using a flexible framework such as mixed logit is important for understanding the strategic responses of firms to changes in taxation and cost as we observe substantial differences in pass-through across the models. The mixed logit predicts significant heterogeneity in pass-through across products while the pseudo nested logit and multinomial logit uniformly predict under-shifted pass-through. These results suggest that the estimated own-product demand curvature plays the major role in determining pass-through, while the indirect impact of competing products and their curvature plays a minor role. An important modeling choice to recall is that the mixed logit nests the other models so the pass-through rates implied by the pseudo nested logit and multinomial logit models are restrictions imposed by the researcher ex ante.

4.3. Merger analysis

In Fig. 4 we use the estimated models to simulate a merger between the two largest firms.[16] As with the cost increase experiment, we observe that the predicted price changes vary substantially between estimated models. The mixed logit and "demographics" model specifications predict both larger upward pricing pressure (i.e.larger predicted changes in price) overall and greater heterogeneity in price changes than the pseudo nested logit and multinomial logit models. These large and diverse predictions translate into larger and more heterogeneous cost reductions required to keep consumers indifferent between the pre- and post-merger environments. These results are particularly interesting since researchers tend to prefer a nested logit not only for its simplicity, but also for its ability to generate more realistic substitution patterns. Figure 4 demonstrates that the log-concavity of nested logit may nonetheless materially affect inference about the implications of mergers.

5. Concluding remarks

Pass-through is key to the analysis of tax incidence and welfare implications of horizontal mergers. We have reviewed the role of demand curvature for pass-through when firms have market power and have highlighted properties of the demand specification that drive curvature in popular discrete choice models of demand. Our empirical case study, focusing on the ready-to-eat cereal market, highlights the limitations of using simpler logit and nested logit models to accurately estimate pass-through rates. These limitations become particularly pronounced when the underlying demand for products exhibits substantial variation in curvature or curvatures that exceed one. A mixed logit specification estimated on the same data generates a wider range of curvatures and implies over-shifting of cost pass-through for a sizable share of products. Outside of the quasi-linear utility set-up we consider, Griffith et al. (2018) point out that including income effects can deliver estimates of demand curvature greater than one. Such a modeling choice may make sense when considering the choice of an expensive product such as an automobile (e.g. Berry et al., 1995), relative to the consumer packaged goods we consider. While working with mixed logit models in the past was burdensome, recent efforts at improving instruments and identification (Reynaert and Verboven, 2013, Gandhi and Houde, 2020, Berry and Haile, 2022) as well as standardized estimation routines (Conlon and Gortmaker, 2020) have lowered the computational burden of estimating these models, allowing for example large-scale estimation of mixed logit models across industries (Doepper et al., 2023). The results here demonstrate the clear gains from their use, not just in estimating realistic substitution patterns, but also in flexibly accommodating economically meaningful demand curvature.

[16] We attain similar results for alternative mergers, though the difference in magnitudes between models shrink as a merger between smaller competitors generates less upward pricing pressure.

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Eugenio J. Miravete: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Katja Seim:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Jeff Thurk:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

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