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Abstract

How does market power affect the rate of pass-through from marginal cost to the market price? A standard intuition is that more competition makes prices more "cost-reflective" and thus raises cost pass-through. This paper shows that this intuition is sensitive to the common assumption in the literature that firms' marginal costs are constant. If firms have even modestly increasing marginal costs, more intense competition actually reduces pass-through. These results apply to the "normal" case where pass-through is less than 100%. They have implications for competition policy and environmental regulation.

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*All views expressed and any errors are mine.

1 Introduction

In recent years, there has been a resurgence of interest in cost pass-through as tool to understand market performance and the effects of policy interventions across a wide range of fields in economics including industrial organization, public economics, and international trade (Weyl & Fabinger 2013).

How does competition affect pass-through? A common intuition is that firms with market power have an incentive to "absorb" part of a cost change whereas, under perfect competition, price equals marginal cost so pass-through is 100%. This suggests that more intense competition leads to stronger pass-through. Perhaps most prominently, this intuition holds in a textbook linear Cournot model, with 50% pass-through under monopoly which rises up to 100% as the number of firms grows large.

Yet this intuition and the existing literature on pass-through under imperfect competition (e.g., Bulow & Pfleiderer 1983; Kimmel 1992; Anderson & Renault 2003; Weyl & Fabinger 2013; Mrázová & Neary 2017) maintain the assumption that firms have constant marginal costs. On one hand, this is a substantive economic assumption which may be appropriate for some markets but less so for others. On the other hand, it obscures the comparison with the benchmark of perfect competition—precisely because it restricts competitive pass-through to a "knife-edge" rate of 100%.

This paper revisits the basic question of how competition affects cost pass-through. It generalizes earlier results from the pass-through literature and highlights their sensitivity to the assumption of constant marginal cost. The model has two key features. First, to facilitate the comparison with perfect competition, the industry sells a homogenous product and the setup nests monopoly, oligopoly and perfect competition as special cases. Second, firms have convex cost functions, which can be justified purely on technology grounds or by invoking the frictions that arise from principal-agent problems within the firm (see especially Hart 1995).

The main point is that, if firms have even modestly increasing marginal costs, the standard intuition is overturned—and more intense competition actually *reduces* pass-through. A less flexible production technology, with more steeply increasing marginal cost, always leads to lower pass-through. This holds in a textbook model of perfect competition and extends to imperfect competition. However, the effect is stronger for a more competitive market because it has higher industry output. This helps explains why, in markets with a fairly inflexible production technology, more competition can be associated with less pass-through. Importantly, these results apply to the "normal" case where pass-through is less than 100%.

Consider comparing two markets with different intensities of competition. For a like-for-like comparison, suppose that any differences in demand and cost conditions are controlled for. The analysis shows that, under plausible conditions, the more competitive market always has lower pass-through if cost convexity is sufficiently pronounced. For example, if demand is strictly convex and firms' cost functions are at least quadratic, then the more competitive market passes on less of a (small) cost increase.

From a policy perspective, questions about pass-through and market power are especially salient across the energy industry. Pass-through of fuel costs to retail electricity prices has been an important concern of competition policy in the UK electricity sector (CMA 2015). Similarly, the extent to which a carbon price imposed on energy-intensive (and often significantly concentrated) industries such as electricity, cement and steel is passed onto market prices is central to the effectiveness of market-based regulation towards climate change (Fabra & Reguant 2014).

Section 2 sets up the model, and Section 3 presents a unifying equilibrium result on cost pass-through that holds under perfect and imperfect competition. Section 4 presents conditions under which more competition leads to lower cost pass-through, and Section 5 gives two illustrative examples. Section 6 concludes.

2 The model

Consider a simple model of imperfect competition between n symmetric firms that nests perfect competition and monopoly as special cases.

The inverse demand curve is $p(X)$, where p is the market price, X is industry output and $p'(\cdot) < 0$. Let $\varepsilon^D \equiv -p(X)/Xp'(X) > 0$ be the price elasticity of demand and let $\xi^D \equiv -Xp''(X)/p'(X)$ be a measure of demand curvature. Demand is concave if $\xi^D \leq 0$ and convex otherwise; it is log-concave (i.e., the log of direct demand $\ln D(p)$ is concave in p) if $\xi^D \leq 1$ and log-convex otherwise.

Demand curvature can also be expressed as $\xi^D = 1 + (1 - \psi^D)/\varepsilon^D$, where $\psi^D \equiv p[d\varepsilon^D(p)/dp]/\varepsilon^D(p)$ is the superelasticity of demand, i.e., the elasticity of the elasticity (Kimball 1995). So demand is log-concave $\xi^D \leq 1$ if and only if it is superelastic $\psi^D \geq 1$.

Firm i has a cost function $\widehat{C}(x_i) \equiv [C(x_i) + \tau x_i]$ where x_i is its output (so $X \equiv \sum_i x_i$), τ is a cost shifter, and which satisfies $C'(\cdot) > 0, C''(\cdot) \geq 0$ (where $\widehat{C}''(x_i) = C''(x_i)$). Let $\eta_i^S \equiv x_i \widehat{C}''(x_i)/\widehat{C}'(x_i) \geq 0$ be the elasticity of i's marginal cost which, given symmetry, will be identical across firms with $\eta_i^S = \eta^S$. This can be seen as a measure of the "inflexibility" of the production technology.

Remark 1. The model defines the elasticity of firm i's marginal cost $\widehat{C}'(x_i)$ *including* the cost shifter τ. Many papers on pass-through focus on the case in which the initial value of the cost shifter is zero, $\tau = 0$. Then marginal cost is (locally) identical including and excluding the cost shifter $\widehat{C}'(x_i) = C'(x_i)$, and so the cost elasticity $\eta_i^S = x_i C''(x_i)/C'(x_i)$ can equivalently be written without the cost shifter.[1] This paper does not restrict atten-

[1] More generally, they are related according to $\eta_i^S = [x_i C''(x_i)/C'(x_i)] \,/\, [1 + \tau/C'(x_i)]$.

tion to $\tau = 0$, though its findings also apply to this case.

Firm i's profits are given by $\Pi_i = p(X)x_i - C(x_i) - \tau x_i$. Each firm chooses its quantity x_i in a generalized version of Cournot competition. The industry's conduct parameter $\theta \in [0,1]$ serves as a summary statistic of the intensity of competition. Formally, firms' equilibrium outputs $(x_i^*)_{i=1\ldots n}$ satisfy:

$$x_i^* = \arg\max_{x_i \geq 0} \{p(\theta(x_i - x_i^*) + X^*)x_i - C(x_i) - \tau x_i\}. \tag{1}$$

Firm i, in deviating its output by $(x_i - x_i^*)$, conjectures that industry output will change by $\theta(x_i - x_i^*)$ as a result. In this "conduct equilibrium", lower values of θ correspond to more intense competition. This setup can be viewed as a reduced-form representation of a dynamic game (Cabral 1995). The Cournot-Nash equilibrium, where each firm takes its rivals' output as given, occurs where $\theta = 1$, and perfect competition where $\theta = 0$.

Two regularity conditions will ensure a well-behaved interior equilibrium. First, a sufficient condition for an interior equilibrium is that $p(0) > \widehat{C}(0) = C'(0) + \tau$. Second, the condition $\xi^D < 2$, such that the industry's marginal revenue is downward-sloping, will ensure a well-behaved equilibrium, regardless of the intensity of competition.

The first-order condition for firm i is:

$$p(X) + \theta x_i p'(X) - \widehat{C}'(x_i) = 0 \text{ at } x_i = x_i^*. \tag{2}$$

This says that a generalized version of firm i's marginal revenue equals its marginal cost.[2] In symmetric equilibrium, $X^* = nx^*$, and so the first-order condition becomes:

$$p(nx^*) + \theta x^* p'(nx^*) - \widehat{C}'(x^*) = 0. \tag{3}$$

Let $\widehat{\theta}^S \equiv (\theta/n)$ be an index of market power which is higher with a larger conduct parameter and/or fewer firms. Writing $p(\widehat{\theta}^S)$ for the equilibrium price, the role of this index is made precise as follows:

Lemma 1 *The equilibrium elasticity-adjusted Lerner index* $L \equiv \varepsilon^D[p(X) - \widehat{C}'(x)]/p(X) = \widehat{\theta}^S \in [0,1]$*, where the equilibrium market price* $p(\widehat{\theta}^S)$ *rises with* $\widehat{\theta}^S$.

The setup facilitates comparative statics on competition via changes in $\widehat{\theta}^S$ (where both θ and n are exogenous). As expected, less intense competition leads to a higher market price (and lower industry output). Note also that, at equilibrium, the price elasticity of demand cannot be too low, with $\varepsilon^D > \widehat{\theta}^S$ (and so $\varepsilon^D > 1$ for monopoly).

[2] The second-order condition for firm i is: $(1+\theta)p'(X) + \theta p''(X)x_i - C''(x_i) < 0 \Leftrightarrow (1+\theta) - (x_i/X)\theta\xi + C''(x_i)[-p'(X)] > 0$, which is always satisfied given that $\theta \in [0,1]$, $\xi^D < 2$, $x_i/X \in (0,1)$, $C''(x_i) \geq 0$ and $p'(X) < 0$.

3 Equilibrium cost pass-through

The analysis begins by deriving an expression for cost pass-through: the change in the equilibrium market price arising from a market-wide rise in marginal cost, $\rho \equiv dp/d\tau$.

Lemma 2 *The equilibrium rate of cost pass-through equals:*

$$\rho(\varepsilon^D, \xi^D, \eta^S, \widehat{\theta}^S) = \frac{1}{\left[1 + (\varepsilon^D - \widehat{\theta}^S)\eta^S + \widehat{\theta}^S(1 - \xi^D)\right]} > 0.$$

The expression for pass-through from Lemma 2 nests various results from prior literature.[3] First, under perfect competition ($\widehat{\theta}^S = 0$), the first-order condition (2) defines firm i's supply curve; letting $\varepsilon_i^S \equiv px_i'(p)/x_i(p) > 0$ be firm i's price elasticity of supply, at symmetric equilibrium, $\varepsilon_i^S = \varepsilon^S$ and $\eta^S = 1/\varepsilon^S$. This leads to the textbook result that competitive pass-through $\rho = \varepsilon^S/(\varepsilon^S + \varepsilon^D)$ is driven by the ratio of demand and supply elasticities—and is never greater than 100%.

Second, under monopoly (Bulow & Pfleiderer 1983) or monopolistic competition (Mrázová & Neary 2017) with constant marginal cost ($n = 1$, $\theta = 1$, $\eta^S = 0$), pass-through $\rho = 1/(2 - \xi^D)$ is determined solely by demand curvature ξ^D—with no distinct role for the price elasticity of demand ε^D.

Third, under Cournot-Nash competition (Kimmel 1992) with constant marginal cost ($\theta = 1$, $\eta^S = 0$), pass-through $\rho = 1/[1+\widehat{\theta}^S(1-\xi^D)]$ is additionally determined by market structure—as then given by the competition index $\widehat{\theta}^S \equiv (1/n)$.

Lemma 2 shows that, more generally, pass-through is determined by four factors: the price elasticity of demand ε^D, demand curvature ξ^D, the elasticity of marginal cost η^S, and the intensity of competition $\widehat{\theta}^S$. The role of the demand elasticity ε^D is predicated on the presence of the cost elasticity, $\eta^S > 0$, which is often assumed away in prior literature.

It is easy to see that pass-through, in general, is always lower for a less flexible production technology, that is, $\partial\rho/\partial\eta^S < 0$, all else equal. In this sense, a basic insight from perfect competition extends to settings with imperfect competition. In the limit, pass-through tends to zero, $\rho \to 0$, as technology becomes entirely inflexible, $\eta^S \to \infty$, for example, because firms face binding capacity constraints. In such a situation, the change in marginal cost induces no change in output—and hence also no price change.

It is well-known that, under imperfect competition, it is possible for pass-through to exceed 100%. Proposition 1 makes precise that this occurs whenever $\widehat{\theta}^S(\xi^D - 1) \geq \eta^S(\varepsilon^D - \widehat{\theta}^S)$. Several things are needed: (i) there is market power $\widehat{\theta}^S > 0$; (ii) demand is log-convex $\xi^D > 1$ (equivalently, superinelastic $\psi^D < 1$); and (iii) the elasticity of

[3] To my best knowledge, Lemma 2's expression for pass-through is a new result, precisely because it allows for both *both* convex costs, $\eta^S > 0$, and market power, $\widehat{\theta}^S > 0$.

marginal cost η^S cannot be too large (for example, if $\eta^S > \max\{0, (\varepsilon^D - 1)^{-1}\} \equiv \underline{\eta}^S$ then $\rho < 1$ for any $\widehat{\theta}^S \in [0, 1]$ and $\xi^D < 2$).

4 Does competition increase pass-through?

What is the equilibrium impact of more competition on cost pass-through? Answering this question requires some care because varying the intensity of competition via $\widehat{\theta}^S$ can, in general, also affect the (equilibrium) values of the demand and cost parameters $(\varepsilon^D, \xi^D, \eta^S)$ as none of these are necessarily constants.

Two approaches are presented. First, the "cross section" approach compares pass-through in two different markets on a like-for-like basis, where one market is more competitive than the other but identical in terms of $(\varepsilon^D, \xi^D, \eta^S)$. Second, the "time series" approach compares pass-through in the same market following an exogenous increase in its intensity of competition, taking into account any knock-on effects on $(\varepsilon^D, \xi^D, \eta^S)$.

Under both approaches, it will turn out that cost convexity makes the standard intuition—more competition raises pass-through—quite fragile.

4.1 Varying competition between markets

Consider two markets, 1 and 2, with different values of the intensity of competition, $\widehat{\theta}_1^S$ and $\widehat{\theta}_2^S$, where $\widehat{\theta}_1^S < \widehat{\theta}_2^S$. Firm conduct is more competitive in market 1 because there are more firms or because rivalry is more intense for the same number of firms.

The markets may differ in terms of their demand and cost *functions*. Lemma 2 makes clear that the relevant demand and cost conditions for pass-through are given by $(\varepsilon^D, \xi^D, \eta^S)$. The idea here is that an econometric analysis will control for any differences between the markets in terms of the values of $(\varepsilon^D, \xi^D, \eta^S)$.

Proposition 1 *Consider two markets* 1 *and* 2 *with identical demand conditions (as given by* ε^D, ξ^D*) and cost conditions (as given by* η^S*) where market* 1 *is more competitive than market* 2 *with* $\widehat{\theta}_1^S < \widehat{\theta}_2^S$*. Equilibrium cost pass-through is lower in the more competitive market* 1*,* $\rho(\widehat{\theta}_1^S) < \rho(\widehat{\theta}_2^S)$*, if and only if demand and cost conditions satisfy:*

$$\eta^S + \xi^D > 1,$$

which always holds for a sufficiently large elasticity of marginal cost η^S*.*

Proposition 1 yields the opposite of the standard intuition that more competition leads to higher pass-through. All else equal, whenever costs are sufficiently convex in that $\eta^S > 1 - \xi^D$, pass-through is *lower* in the market with more intense competition. For example, the condition always holds for pass-through $\rho|_{\tau \to 0}$ of a small new tax if demand

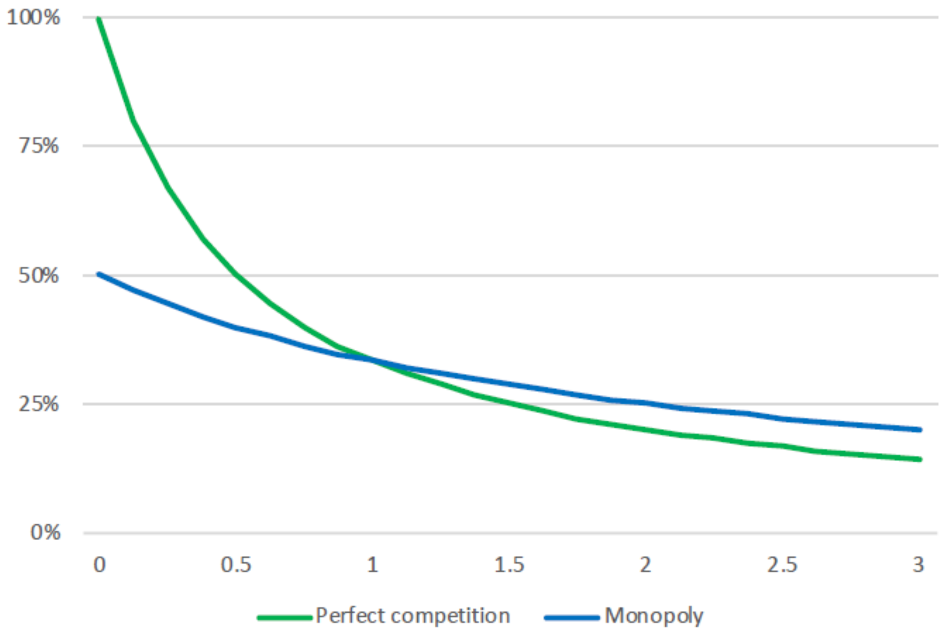

Figure 1: Equilibrium cost pass-through ρ for different elasticities of marginal cost η^S under perfect competition ($\widehat{\theta}_1^S = 0$) and monopoly ($\widehat{\theta}_2^S = 1$)

is strictly convex $\xi^D > 0$ and costs are at least as convex as a quadratic cost function, $C(x_i) = kx_i^2$ (as then $\eta^S \geq 1$). More generally, the condition always holds for a sufficiently large η^S, regardless of demand conditions and competitive intensity.

In the special case with constant marginal cost, $\eta^S = 0$, the condition from Proposition 1 boils down to demand being log-convex $\xi^D > 1$ (equivalently, superinelastic $\psi^D < 1$). In such circumstances, therefore, *both* markets feature pass-through in excess of 100% but it is closer to 100% in the more competitive market, $\rho(\widehat{\theta}_2^S) > \rho(\widehat{\theta}_1^S) > 1$.

By contrast, with non-constant marginal cost, $\eta^S > 0$, more competition can yield lower pass-through even in the "normal" case in which it lies below 100%.

Figure 1 illustrates Proposition 1 by plotting pass-through ρ against the cost elasticity η^S for the two polar cases: perfect competition in market 1 ($\widehat{\theta}_1^S = 0$) and monopoly in market 2 ($\widehat{\theta}_2^S = 1$). Demand is taken to be linear $\xi^D = 0$ with a price elasticity of demand (at equilibrium) set at $\varepsilon^D = 2$. For "small" cost elasticities, $\eta^S \leq 1$, pass-through rates are higher in the competitive market $\rho(\widehat{\theta}_1^S) \geq \rho(\widehat{\theta}_2^S)$. This is in line with the standard intuition. However, for "large" cost elasticities, $\eta^S > 1$, this relationship flips to $\rho(\widehat{\theta}_1^S) < \rho(\widehat{\theta}_2^S)$ and it is the monopoly market that features stronger pass-through. This is the opposite of the standard intuition. (In the limiting case as $\eta^S \to \infty$, pass-through converges to zero for both market structures.)

What is driving this result? Recall that a less flexible production technology always means lower pass-through, $\partial\rho/\partial\eta^S < 0$. A key observation is that this effect is mitigated by market power in the following sense:

Lemma 3. *Equilibrium cost pass-through satisfies*

$$\frac{\partial}{\partial \widehat{\theta}^S}\left[\frac{\partial}{\partial \eta^S}\rho(\varepsilon^D, \xi^D, \eta^S, \widehat{\theta}^S)\right] \geq 0$$

if and only if the cost elasticity satisfies $\eta^S \leq [1+(1-\xi^D)(2\varepsilon^D - \widehat{\theta}^S)]/(\varepsilon^D - \widehat{\theta}^S)$*, for which* $\eta^S \leq 1-\xi^D$ *is a sufficient condition.*

Lemma 3 shows that, for modest values of η^S, the pass-through function is supermodular in the cost elasticity and market power. A less flexible production technology means lower pass-through—and more strongly so for a more competitive market. This helps explains why, in markets with a fairly inflexible production technology, more competition can be associated with less pass-through.

4.2 Varying competition within a market

Now consider the second approach: the same market, with the same demand and cost functions, is observed "over time" and competition (exogenously) intensifies, as measured by a lower $\widehat{\theta}^S$. Write the price in terms of the conduct parameter $p(\widehat{\theta}^S)$, and think of the (equilibrium) values of the demand and cost parameters as $(\varepsilon^D(p(\widehat{\theta}^S)), \xi^D(p(\widehat{\theta}^S)), \eta^S(p(\widehat{\theta}^S))$. How does more competition affect pass-through?

Let $\phi_i^S \equiv x_i C'''(x_i)/C''(x_i)$ be the elasticity of the *slope* of i's marginal cost which, given symmetry, will again be identical across firms with $\phi_i^S = \phi^S$ (also recalling that $\widehat{C}''(\cdot) = C''(\cdot)$ and $\widehat{C}'''(\cdot) = C'''(\cdot)$).

Proposition 2. *(a) Equilibrium cost pass-through is lower with more competition,* $d\rho(\widehat{\theta}^S)/d\widehat{\theta}^S > 0$*, if and only if demand and cost conditions and firm conduct satisfy:*

$$\frac{(\varepsilon^D - \widehat{\theta}^S)\eta^S}{\left[1+\widehat{\theta}^S(1-\xi^D)+(\varepsilon^D-\widehat{\theta}^S)\eta^S\right]}(\phi^S+\xi^D) > \frac{d}{d\widehat{\theta}^S}\left[\widehat{\theta}^S(1-\xi^D)\right],$$

which always holds for sufficiently large elasticities of marginal cost η^S *and its slope* ϕ^S*;*
(b) Equilibrium cost pass-through lies below 100%, $\rho(\widehat{\theta}^S) \leq 1$*, and is lower with more competition* $d\rho(\widehat{\theta}^S)/d\widehat{\theta}^S > 0$ *if:*

- *Demand is log-concave* $\xi^D \leq 1$ *(equivalently, superelastic* $\psi^D \geq 1$*) and demand curvature is non-decreasing* $d\xi^D(p)/dp \geq 0$*;*
- *Costs are sufficiently convex in that* (η^S, ϕ^S) *satisfy* $(\varepsilon^D - \widehat{\theta}^S)\eta^S(\phi^S + 2\xi^D - 1) > (1-\xi^D)[1+\widehat{\theta}^S(1-\xi^D)]$ *for which* $\eta^S > 0$ *and* $\phi^S > (1-2\xi^D)$ *are then necessary.*

Proposition 2 delivers a similar conclusion to Proposition 1: Under plausible conditions, more competition reduces pass-through—and the standard intuition is overturned.

There is a simple set of sufficient conditions. First, demand is log-concave, which is a common assumption in economic theory (e.g., Bagnoli & Bergstrom 2005), and is more convex at a higher price $d\xi^D(p)/dp \geq 0$, which applies, for example, for any demand curve of the family $p(X) = \alpha - \beta X^\gamma$, which has constant curvature $\xi^D = 1 - \gamma$. Second, firms' costs and marginal costs are sufficiently convex, that is, $\eta^S > 0 \Leftrightarrow C''(\cdot) > 0$ and $\phi^S > 0 \Leftrightarrow C'''(\cdot) > 0$ are both positive and sufficiently large.

To see the role of sufficient cost convexity, consider a market with a single firm and linear demand ($n = 1$, $\xi^D = 0$). Initially the firm is a price-taker ($\widehat{\theta}^S = 0$) and then it becomes a monopolist ($\widehat{\theta}^S = 1$). Let $x^c \equiv x(0)$ denote the competitive output and $x^m \equiv x(1)$ the monopoly output, where $x^m < x^c$. Cost pass-through under monopoly ρ^m is higher than with perfect competition ρ^c whenever:

$$\rho^m = \frac{1}{\left[2 + \dfrac{C''(x^m)}{\beta}\right]} > \frac{1}{\left[1 + \dfrac{C''(x^c)}{\beta}\right]} = \rho^c$$

which holds if and only if $\int_{x^m}^{x^c} C'''(y)dy = [C''(x^c) - C''(x^m)] > \beta$. So competition reduces pass-through if $C''(\cdot) > 0$ and $C'''(\cdot)$ is large enough. The condition from Proposition 2 provides a general result for the case of a small change in competitive intensity.

5 Illustrative examples

A couple of examples are useful to illustrate the issues that arise and the differences between the "cross section" and "time series" approaches. For simplicity, these examples consider pass-through $\rho|_{\tau=0}$ where the initial value of the cost shifter is zero.

Example 1. Demand is linear $p(X) = \alpha - \beta X$ while firms' cost functions are quadratic $C(x_i) = kx_i^2$. This corresponds to $\xi^D = 0$ and $\eta^S = 1$. Using Lemma 2, pass-through $\rho|_{\tau=0} = (1 + \varepsilon^D)^{-1} < 1$ then is always incomplete—and depends directly only on the demand elasticity ε^D.

Between markets: Conditional on the demand elasticity ε^D, competition has zero impact on pass-through in the cross section, i.e., $\rho(\widehat{\theta}_1^S) = \rho(\widehat{\theta}_2^S)$. This is a knife-edge case of the condition of Proposition 1. This is at least partly inconsistent with the standard intuition.

Within market: With linear demand, the elasticity $\varepsilon^D(p(\widehat{\theta}^S))$ itself varies along the demand curve—with a positive superelasticity $\psi^D = 1 + \varepsilon^D > 0$. So a higher $\widehat{\theta}^S$ implies a higher price $p(\widehat{\theta}^S)$, a higher elasticity $\varepsilon^D(p(\widehat{\theta}^S))$, and hence lower pass-through with $d\rho(\widehat{\theta}^S)/d\widehat{\theta}^S < 0$, thus violating the condition of Proposition 2. So here competition increases pass-through via a demand-superelasticity channel. This is in line with the standard intuition.

Example 2. Demand is exponential $p(X) = \alpha - \beta \log X$ and firms' cost functions have constant elasticity $C(x_i) = kx_i^{\lambda}$, with $\lambda > 1$. This corresponds to $\xi^D = 1$ (equivalently, unit superelasticity $\psi^D = 1$) and $\eta^S = \lambda - 1 > 0$. Using Lemma 2, pass-through $\rho|_{\tau=0} = [1 + (\varepsilon^D - \widehat{\theta}^S)(\lambda - 1)]^{-1} < 1$ is again always incomplete but now also more involved.

Between markets: Conditional on the demand elasticity ε^D and the cost elasticity λ, the more competitive market 1—by inspection or by Proposition 1—always has lower pass-through in the cross section, i.e., $\rho(\widehat{\theta}_1^S) < \rho(\widehat{\theta}_2^S)$ This is the opposite of the standard intuition.

Within market: Pass-through declines with more competition, $d\rho(\widehat{\theta}^S)/d\widehat{\theta}^S > 0$, whenever $\frac{d}{d\widehat{\theta}^S}[\widehat{\theta}^S - \varepsilon^D(p(\widehat{\theta}^S))] > 0$. It is easy to check that $d\varepsilon^D(p(\widehat{\theta}^S))/d\widehat{\theta}^S = \rho$, so the condition of Proposition 2 always holds. So here competition reduces pass-through via a competition-plus-demand channel. This is again the opposite of the standard intuition.

6 Conclusions and policy implications

Existing literature on imperfect competition typically assumes that firms have constant marginal costs. As a result, pass-through analysis has focused on demand-side properties. More competition then raises pass-through as long as it lies below 100%.

This paper has shown that this result is perhaps surprisingly fragile. If firms have increasing marginal costs, then more competition may reduce pass-through. A rough intuition is that a more competitive industry has higher output, and with convex costs is therefore more exposed to a cost increase.

These results may have implications for competition policy, for example, for understanding how cost savings from horizontal mergers are passed on to consumers and for evaluating the "passing-on defense" (Verboven & Van Dijk 2009) whereby cartel damages are limited because affected firms pass the overcharge onto their own customers.

In a more competitive market, the market price will be more reflective of marginal cost. It does not follow that price changes will necessarily be more reflective of cost changes.

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Appendix

Proof of Lemma 1. The expression for $L \equiv \varepsilon^D[p(X) - \widehat{C}'(x)]/p(X)$ follows by rearranging (3) and using the definitions of ε^D and $\widehat{\theta}^S$. Differentiating (3) shows that:

$$\begin{aligned} \frac{dp(\widehat{\theta}^S)}{d\widehat{\theta}^S} &= p'(X)n\frac{dx}{d\widehat{\theta}^S} = p'(X)n\frac{p'(X)X}{-[p'(X)n + \theta p'(X) + \theta nxp''(X) - C''(x)]} \\ &= -p'(X)X\frac{n}{\left[(n+\theta) - \theta\xi^D - C''(x)/p'(X)\right]} > 0, \end{aligned} \tag{4}$$

where the denominator of this expression is positive because $(n+\theta) > \theta\xi^D$ given that $n \geq 1$, $\theta \in [0,1]$ and $\xi^D < 2$ as well as $C''(x) \geq 0$ and $p'(X) < 0$.

Proof of Lemma 2. By construction, cost pass-through satisfies $\rho \equiv \frac{dp}{d\tau} = p'(X)n\frac{dx}{d\tau}$. Hence differentiating (3) yields:

$$\rho = \frac{p'(X)n}{[p'(X)n + \theta p'(X) + \theta nxp''(X) - C''(x)]} = \frac{n}{\left[(n+\theta) - \theta\xi^D - C''(x)/p'(X)\right]} > 0, \tag{5}$$

using the definition $\xi^D \equiv -Xp''(X)/p'(X)$ and where the denominator is again positive. Now rewrite the last term as follows:

$$\frac{C''(x)}{-p'(X)} = \frac{x\widehat{C}''(x)}{\widehat{C}'(x)}\frac{\widehat{C}'(x)}{p(X)}\frac{p(X)}{-Xp'(X)}\frac{X}{x} = \eta^S\frac{(\varepsilon^D - \theta/n)}{\varepsilon^D}\varepsilon^D n = \eta^S(\varepsilon^D - \widehat{\theta}^S)n, \tag{6}$$

which uses Lemma 1 and the definitions $\varepsilon^D \equiv -p(X)/Xp'(X)$, $\eta_i^S \equiv x_i\widehat{C}''(x_i)/\widehat{C}'(x_i)$ (at symmetric equilibrium, where $\widehat{C}''(x_i) = C''(x_i)$), and $\widehat{\theta}^S \equiv (\theta/n)$. Combining (5) and (6) and some rearranging yields the expression for $\rho(\varepsilon^D, \xi^D, \eta^S, \widehat{\theta}^S)$.

Proof of Proposition 1. Given the assumptions, follows by inspection of Lemma 2.

Proof of Lemma 3. Differentiating the expression for equilibrium cost pass-through from Lemma 2 gives:

$$\frac{\partial}{\partial\eta^S}\rho(\varepsilon^D, \xi^D, \eta^S, \widehat{\theta}^S) = -\frac{(\varepsilon^D - \widehat{\theta}^S)}{\left[1 + (\varepsilon^D - \widehat{\theta}^S)\eta^S + \widehat{\theta}^S(1-\xi^D)\right]^2} < 0.$$

Differentiating again for the cross-partial effect gives:

$$\frac{\partial}{\partial\widehat{\theta}^S}\left[\frac{\partial}{\partial\eta^S}\rho(\varepsilon^D, \xi^D, \eta^S, \widehat{\theta}^S)\right] = \frac{\left[1 + (\varepsilon^D - \widehat{\theta}^S)\eta^S + \widehat{\theta}^S(1-\xi^D)\right] + 2(1-\xi^D-\eta^S)(\varepsilon^D - \widehat{\theta}^S)}{\left[1 + (\varepsilon^D - \widehat{\theta}^S)\eta^S + \widehat{\theta}^S(1-\xi^D)\right]^3}.$$

It is immediate that $\frac{\partial}{\partial\widehat{\theta}^S}\left(\frac{\partial}{\partial\eta^S}\rho\right) > 0$ if $\eta^S \leq 1 - \xi^D$ and some further rearranging shows that $\frac{\partial}{\partial \widehat{\theta}^S}\left(\frac{\partial}{\partial \eta^S}\rho\right) > 0 > 0$ if and only if $[1 + (1-\xi^D)(2\varepsilon^D - \widehat{\theta}^S)]/(\varepsilon^D - \widehat{\theta}^S)$.

Proof of Proposition 2. For part (a), differentiating the expression for pass-through from Lemma 2 shows that:

$$\frac{d\rho}{d\widehat{\theta}^S} > 0 \text{ if and only if } \frac{d}{d\widehat{\theta}^S}\left[\frac{1}{n}\frac{C''(x)}{-p'(X)}\right] < -\frac{d}{d\widehat{\theta}^S}\left[\widehat{\theta}^S(1-\xi^D)\right].$$

Expanding the first term gives:

$$\begin{aligned}
\frac{d}{d\widehat{\theta}^S}\left[\frac{1}{n}\frac{C''(x)}{-p'(X)}\right] &= \frac{1}{n}\frac{dX}{d\widehat{\theta}^S}\left[\frac{\frac{1}{n}C'''(x) - [-p''(X)]C''(x)}{[-p'(X)]^2}\right] \\
&= \frac{1}{n}\frac{dX}{d\widehat{\theta}^S}\frac{1}{X}\left[\frac{xC'''(x)}{C''(x)} + \frac{p''(X)X}{-p'(X)}\right]\frac{C''(x)}{-p'(X)} \\
&= -\frac{1}{n}\frac{dp}{d\widehat{\theta}^S}\frac{1}{-Xp'(X)}\left[\frac{xC'''(x)}{C''(x)} + \frac{p''(X)X}{-p'(X)}\right]\frac{C''(x)}{-p'(X)} \\
&= -\left[\frac{1}{n}\frac{C''(x)}{-p'(X)}\right](\phi^S + \xi^D)\rho,
\end{aligned}$$

where the last step uses the definitions $\xi^D \equiv -Xp''(X)/p'(X)$ and $\phi_i^S \equiv x_i C'''(x_i)/C''(x_i)$ (at symmetric equilibrium) and combines the result for $dp/d\widehat{\theta}^S$ from Lemma 1, see (4), with the result for ρ from Lemma 2, see (5). Now using $\frac{1}{n}\frac{C''(x)}{-p'(X)} = (\varepsilon^D - \widehat{\theta}^S)\eta^S$ from (6) and the expression for ρ from Lemma 2 gives:

$$\frac{d}{d\widehat{\theta}^S}\left[\frac{1}{n}\frac{C''(x)}{-p'(X)}\right] = -\frac{(\varepsilon^D - \widehat{\theta}^S)\eta^S}{\left[1 + \widehat{\theta}^S(1-\xi^D) + (\varepsilon^D - \widehat{\theta}^S)\eta^S\right]}(\phi^S + \xi^D),$$

and the condition follows immediately as claimed.

For part (b), under the assumption $d\xi^D/dp \geq 0$, it follows that $\frac{d}{d\widehat{\theta}^S}[\widehat{\theta}^S(1-\xi^D)] \leq (1-\xi^D)$ since $dp/d\widehat{\theta}^S > 0$ by Lemma 1. Therefore a sufficient condition for the condition from part (a) is:

$$\frac{(\varepsilon^D - \widehat{\theta}^S)\eta^S}{\left[1 + \widehat{\theta}^S(1-\xi^D) + (\varepsilon^D - \widehat{\theta}^S)\eta^S\right]}(\phi^S + \xi^D) > \frac{d}{d\widehat{\theta}^S}[\widehat{\theta}^S(1-\xi^D)] \geq (1-\xi^D),$$

which can be rearranged as claimed.