Does competition increase pass-through?

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Abstract

In recent years, the literature has seen a surge of interest in pass-through as an economic tool. At the same time, widespread concerns have emerged about the rising market power of firms. How does competition affect pass-through? A standard intuition is that more competition makes prices more cost-reflective and hence raises the rate of cost pass-through. This paper shows this conclusion is sensitive to the routine assumption that firms' marginal costs are constant. With modestly convex costs, market power can raise pass-through (even when it lies below 1). These results have implications for antitrust policy, environmental regulation, and welfare analysis.

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1 Introduction

In recent years, the literature has seen a surge of interest in using cost pass-through as a tool for economic analysis across fields including industrial organization (Weyl & Fabinger 2013), environmental economics (Fabra & Reguant 2014), development economics (Atkin & Donaldson 2015), and international trade (Mrázová & Neary 2017). At the same time, widespread concerns have emerged about the rising market power of firms, as the result of globalization, soft antitrust enforcement, ownership concentration, and other factors (Shapiro 2019; Syverson 2019).

This paper addresses a basic question that links these two themes: how does market power affect pass-through? A common intuition is that firms with market power have an incentive to absorb part of a cost increase whereas, under perfect competition, price equals marginal cost ($P = MC$) so the rate of pass-through of a market-wide (exogenous) increase in marginal cost ($\partial P/\partial MC$) is 1. This suggests that more intense competition leads to stronger pass-through. Perhaps most prominently, this intuition holds in a textbook linear Cournot model, with a pass-through rate of .5 under monopoly which rises up to 1 as the number of firms grows large.

Yet this intuition and existing theory literature on pass-through under imperfect competition (e.g., Bulow & Pfleiderer 1983; Kimmel 1992; Anderson & Renault 2003; Weyl & Fabinger 2013; Mrázová & Neary 2017) routinely 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 1.[1]

This paper unifies earlier results from the pass-through literature and highlights their sensitivity to the assumption of constant marginal cost. The baseline model has two key features. First, to facilitate the comparison with perfect competition, firms sell a homogeneous product and the setup uses a conduct-parameter approach to nest monopoly, Cournot-Nash oligopoly and perfect competition as special cases (Dixit 1986; Cabral 1995; Weyl & Fabinger 2013).[2] Second, firms' cost functions are convex, perhaps due to the presence of fixed factors of production (such as capital) in the short run; for example, firms in resource-intensive industries often face steeply increasing marginal costs as they approach their capacity constraints. Cost convexity may also arise from limits to scaling managerial talent and principal-agent problems

[1] Weyl & Fabinger (2013) allow for convex costs in some parts of their analysis though much of their treatment of oligopoly reverts to constant marginal cost. Adachi & Fabinger (2018) generalize many incidence results to settings with non-constant marginal costs. Spiegel (2021) derives results on the distribution of social surplus under Cournot competition, also with non-constant marginal costs, and shows the critical role played by the Herfindahl index. None of these papers focus specifically on the interplay between pass-through and market power studied in the present paper.

[2] While this approach facilitates comparative statics on the conduct parameter, the results do not hinge on the use of non-Nash conduct parameters. Conduct parameters are useful in practice (Weyl & Fabinger 2013) but subject to critique on theoretical grounds (Dixit 1986); in some models, the use of conjectural variations can be viewed as a reduced-form representation of a dynamic game (Cabral 1995).

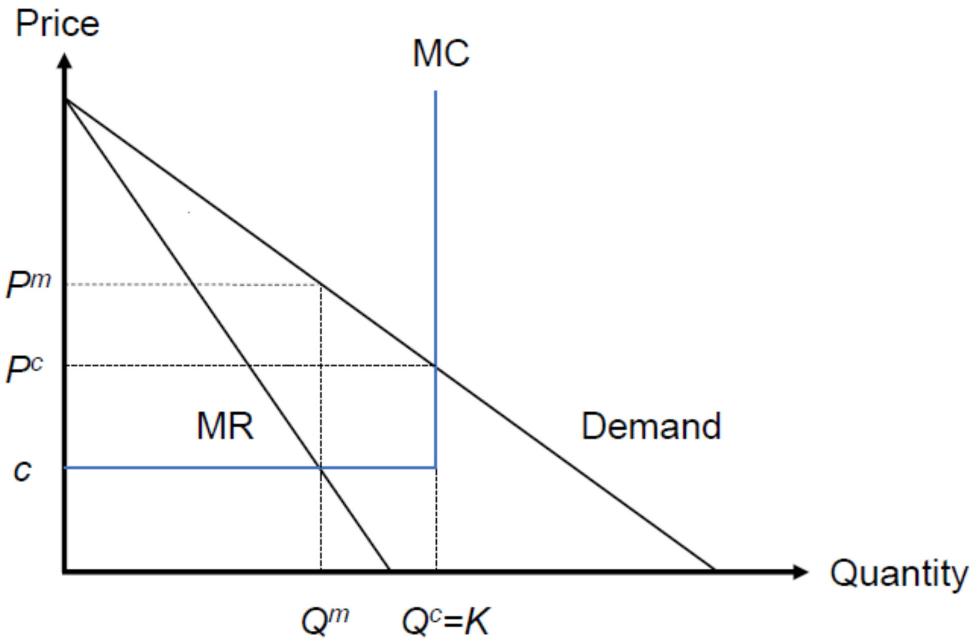

Figure 1. A case in which monopoly cost pass-through exceeds competitive pass-through

within the firm (Hart 1995) or from other frictions in financial and labour markets. In short, “because inputs are scarce, marginal cost is an increasing function of output” (Rotemberg & Woodford 1999).[3]

The main point is that, if firms have even modestly increasing marginal costs, the standard intuition can be overturned—and market power actually increases pass-through. Importantly, this finding applies to the “normal” case where pass-through is incomplete, i.e., lies below 1.

The quickest way to see the result is to look at Figure 1. Market demand (P) is linear and the industry marginal revenue (MR) curve is twice as steep. The marginal cost of production (MC) is a constant c up to the industry's K units of capacity. A monopoly optimally produces $Q^m < K$ units at marginal cost c, leading to the textbook result of a pass-through rate of $\partial P^m/\partial MC = \frac{1}{2}$ $(= \frac{\text{slope of } P(Q)}{\text{slope of } MR(Q)})$. A competitive industry, by contrast, produces at capacity, $Q^c = K$, so its market price does not change and so its rate of pass-through $\partial P^c/\partial MC = 0$ $(= \frac{\text{price elasticity of supply}}{\text{price elasticity of supply}+|\text{price elasticity of demand}|})$. Therefore competition here reduces cost pass-through. Intuitively, a less flexible production technology, with more convex costs, always leads to lower pass-through because it makes quantities—and hence price—less responsive to the cost change. Yet this cost-convexity effect can be more pronounced in a more competitive market as it has higher industry output. While very simple, this point appears to be novel to the literature on price theory.

[3] A different model setup would involve *external* cost constraints in a firm's (competitive) supply chain but retain the assumption of constant marginal cost for the firm itself; this would instead create an endogeneity in that the extent to which upstream suppliers pass on an exogenous cost increase itself depends on the extent of market power at the downstream. The present paper also does not consider the role of input price discrimination by oligopolists.

This paper uses two approaches to present more general versions of this basic insight. First, the "within markets" approach extends the argument in Figure 1 to general demand and cost curves as well as richer market structures. It derives conditions on primitives to characterize when more greater market power increases equilibrium pass-through.[4]

For a softening in competitive conduct—as in Figure 1—sufficient conditions are that (i) the market demand curve is concave, linear or not too convex, (ii) demand is weakly more convex at higher prices, and (iii) cost convexity is pronounced enough.

For a change in market structure—i.e., a smaller number of firms—the conditions to overturn the standard intuition are typically tighter. One reason is that a reduction in the number of firms leads to higher per-firm output—and thus also to greater exposure to the cost constraints that tend to weaken pass-through. Nonetheless, there is a set of cases in which higher-order properties of demand and cost functions overturn the standard intuition.

Second, the "between markets" approach compares in the cross-section two markets that may have different underlying demand and cost functions. For a like-for-like comparison, suppose that any such differences are controlled for—specifically, in the price elasticity of demand, the curvature of demand, and the curvature of the cost function. This yields a very simple condition—similar to the classic Marshall-Lerner condition from international-trade theory—for the more competitive market to have lower pass-through:

$$\frac{\text{elasticity of}}{\text{marginal cost}} + \frac{\text{elasticity of}}{|\text{slope of inverse demand}|} \geq 1.$$

This condition again always holds if cost convexity is sufficiently pronounced; one example is where market demands are linear or convex (but still log-concave) and firms' costs are at least as convex as a quadratic cost function.

In sum, the standard intuition about the relationship between pass-through and market power can be overturned under plausible conditions on demand, costs and conduct.

Section 2 sets up the baseline model, and Section 3 presents a unifying equilibrium result on cost pass-through that applies under both perfect and imperfect competition. Sections 4 and 5 derive, for the two approaches respectively, conditions under which more competition leads to weaker cost pass-through.

Section 6 shows that the main insights from the baseline model also hold under price competition with differentiated products.[5] For the "between markets" approach, the above Marshall-

[4]This paper follows the literature on industrial organization and environmental economics in focusing on the pass-through rate $\partial P/\partial MC$ rather than the elasticity $\partial \ln P/\partial \ln MC$ that is more widely used in macroeconomics and international trade. The condition for market power to raise a pass-through elasticity is tighter due to the higher price-cost mark-up P/MC. However, it is immediate from Figure 1 that the main point can also apply to a pass-through elasticity—which is positive for monopoly but zero under perfect competition.

[5]The present paper does not address the classic question of whether firms prefer price or quantity competition (Singh & Vives 1984; Vives 1985; Leahy & Neary 2021)—and the role of cost structures in shaping this choice (Kreps & Scheinkman 1983; Maggi 1996). Rather it explores how market power affects pass-through and shows

Lerner type condition applies with a straightforward extension of the demand-curvature coefficient to a setting with product differentiation. For the "within market" approach, essentially identical conditions apply in a model with a linear Shubik-Levitan demand system—where greater market power stems from stronger product differentiation or fewer competing firms.

Section 7 discusses the empirical implications of the theory in light of recent econometric work on cost pass-through. Section 8 concludes and outlines policy applications.

2 The model

Consider a simple model of imperfect competition between n symmetric firms that nests perfect competition and monopoly as special cases. Direct demand is $D(p)$ and the corresponding 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., $\ln D(p)$ 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 $\psi^D \equiv [d\varepsilon^D(p)/dp]/[\varepsilon^D(p)/p]$ 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 unit-superelastic $\psi^D \geq 1$.[6]

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 market-wide cost shifter such as a tax or common cost factor, and which satisfies $C'(\cdot) > 0, C''(\cdot) \geq 0$ (where $\widehat{C}''(x_i) = C''(x_i)$). The cost shifter raises marginal cost according to $\partial \widehat{C}'(x_i)/\partial \tau = 1$. 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.[7]

(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, $\tau = 0$, and, for example, a small new unit tax is introduced. 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. This paper

that similar conclusions about the role of cost constraints apply under both modes of competition. One reading of the literature is that environments with significant cost constraints make Cournot competition more likely to emerge as the equilibrium mode of competition; this paper suggests that such environments also make it more likely that standard intuitions on market power and pass-through are overturned. This paper also does not address dynamic considerations related to the speed or frequency of price adjustments.

[6] Mrázová & Neary (2017) use the term "subconvex" for demands with positive superelasticity $\psi^D \geq 0$; this condition is sometimes also referred to as Marshall's "second law of demand."

[7] The assumption of firm symmetry is made for simplicity and is not crucial to the main results. For example, the baseline analysis would extend to marginal-cost asymmetry of the form $C_i'(x_i) = c_i + \mu(x_i)$ (given a fixed number of firms n). Similarly, the analysis would extend to a simple model of vertical product differentiation in which firm i's price $p_i(X) = \sigma_i + p(X)$ reflects its product quality σ_i—even if this would complicate the comparison with the benchmark of perfect competition.

does not restrict attention to $\tau \to 0$, though its findings also apply to this case.)

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

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

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. The Cournot-Nash equilibrium, where each firm takes its rivals' output as given, occurs where $\theta = 1$, and perfect competition with price-taking firms where $\theta = 0$.

Two further conditions will ensure a well-behaved interior equilibrium, regardless of the intensity of competition. First, a sufficient condition for an interior equilibrium is that $p(0) > \widehat{C}(0) = C'(0) + \tau$. Second, the industry's marginal revenue curve is downward-sloping, $\xi^D < 2$.[8]

The first-order condition for firm i is:

$$p(X) + \theta x_i p'(X) - \widehat{C}'(x_i) = 0 \text{ at } x_i = x_i^*. \tag{1}$$

This says that a generalized version of firm i's marginal revenue equals its marginal cost.[9] In symmetric equilibrium, $x_i^* = x^*$, and so the first-order condition becomes:

$$p(nx^*) + \theta x^* p'(nx^*) - \widehat{C}'(x^*) = 0. \tag{2}$$

Let $\theta^S \equiv (\theta/n) \in [0, \frac{1}{n}]$ be an index of market power which is higher with softer conduct or fewer firms. The setup facilitates comparative statics on market power via a change in the value of θ^S, due to a change in competitive conduct θ and/or in market structure n. Write $p(\tau, \theta^S)$ for the equilibrium price (and drop asterisks again for notational simplicity).

The equilibrium elasticity-adjusted Lerner index $L \equiv \varepsilon^D(p - \widehat{C}')/p = \theta^S \in [0, 1]$ so greater market power directly corresponds to a higher L. At equilibrium, the price elasticity of demand cannot be too low, with $\varepsilon^D > \theta^S$ (and so $\varepsilon^D > 1$ for monopoly).

3 Equilibrium cost pass-through

This section derives a unifying expression for pass-through that holds under both perfect and imperfect competition. The rate of cost pass-through is defined as the change in the equilibrium market price arising from a small market-wide shift in marginal cost, $\rho \equiv \partial p(\tau, \theta^S)/\partial\tau$.

[8]The model setup with increasing *marginal* cost would also be compatible with decreasing *average* cost due to the presence of a fixed cost as long as the equilibrium remains interior.

[9]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 the assumptions $\theta \in [0, 1]$, $\xi^D < 2$, $C''(x_i) \geq 0$.

Lemma 1. *The equilibrium rate of cost pass-through equals:*

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

Lemma 1 gives a simple expression for pass-through in terms of familiar elasticity and curvature metrics that encompasses various results from prior literature. First, under perfect competition ($\theta^S = 0$), the first-order condition (1) 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 1.

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.[10]

Third, under Cournot-Nash competition (Kimmel 1992; Atkin & Donaldson 2015) with constant marginal cost ($\theta = 1$, $\eta^S = 0$), pass-through $\rho = 1/[1 + \theta^S(1 - \xi^D)]$ is additionally determined by market structure—as then given by $\theta^S \equiv (1/n)$.

Lemma 1 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 θ^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 based on imperfect competition.[11]

All else equal, pass-through is always lower for a less flexible production technology, that is, $\partial\rho/\partial\eta^S < 0$. In this sense, a basic insight from perfect competition extends to settings with market power. In the limiting case, 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 (as in Figure 1). In such a situation, the change in marginal cost induces no change in output—and hence also no price change.

As is well-known, it is possible for pass-through under imperfect competition to exceed 1. Lemma 1 makes precise that this occurs whenever $\theta^S(\xi^D - 1) \geq \eta^S(\varepsilon^D - \theta^S)$. Several things are needed: (i) there is market power $\theta^S > 0$; (ii) demand is log-convex $\xi^D > 1$ (equivalently, unit-superinelastic $\psi^D < 1$); and (iii) the elasticity of marginal cost η^S cannot be too large (for example, if $\eta^S \geq \max\{0, (\varepsilon^D - 1)^{-1}\} \equiv \underline{\eta}^S$ then $\rho \leq 1$ for any $\theta^S \in [0, 1]$ and $\xi^D < 2$).

A sufficient condition for the "normal" case with pass-through below 1 to obtain, for any

[10] For constant-elasticity demand, $\xi^D = 1 + 1/\varepsilon^D$, so the two parameters directly imply one another.

[11] To the best of my knowledge, the particular way of writing equilibrium cost pass-through in Lemma 1 is a new result. Weyl & Fabinger (2013) obtain the same underlying characterization of pass-through, instead written in terms of the elasticity of marginal consumer surplus.

competitive conduct and cost conditions, is that the demand curve is log-concave, with $\xi^D \leq 1$. This is a common assumption across different fields of economic theory (Bagnoli & Bergstrom 2005) and is met by any demand curve that is concave, linear or not too convex.

4 Pass-through "between markets"

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 θ^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 "between markets" approach in this section compares pass-through in two different markets on a like-for-like basis in the cross section, where one market is more competitive than the other but identical in terms of $(\varepsilon^D, \xi^D, \eta^S)$. Second, the "within market" approach in the next section compares pass-through in the same market following an exogenous increase in its intensity of competition, as in Figure 1, taking into account any knock-on effects on $(\varepsilon^D, \xi^D, \eta^S)$. Under both approaches, it will turn out that cost convexity renders the standard intuition—more competition raises pass-through—quite fragile.

Consider two markets, 1 and 2, with different values of the intensity of competition, θ_1^S and θ_2^S, where $\theta_1^S < \theta_2^S$. Firm conduct is more competitive in market 1 because there are more firms (higher n) or because rivalry is more intense for the same number of firms (lower θ).

The markets may differ in terms of their demand and cost *functions*. Lemma 1 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 their values of $(\varepsilon^D, \xi^D, \eta^S)$.

Direct comparison of the pass-through rates using Lemma 1 yields the following result:

Proposition 1 *Consider two markets* 1 *and* 2 *with the same demand conditions (as given by the demand elasticity* ε^D *and demand curvature* ξ^D*) and cost conditions (as given by cost elasticity* η^S*) where market* 1 *is more competitive than market* 2 *with* $\theta_1^S < \theta_2^S$*. Equilibrium cost pass-through is lower in the more competitive market,* $\rho(\theta_1^S) \leq \rho(\theta_2^S)$*, if and only if demand and cost conditions satisfy:*

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

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

Proposition 1 yields the opposite of the standard intuition: whenever costs are sufficiently convex, pass-through is lower in the market with more intense competition. If demand is linear, with $\xi^D = 0$, the condition boils down to whether the elasticity of marginal cost is at least unity, $\eta^S \geq 1$. Roughly put, cost convexity dampens pass-through and a more competitive market is more exposed it. Importantly, this finding obtains even in the "normal" case where pass-through always lies below 1.

Observe also that the result does not hinge on the conduct-approach taken in the model; it would apply also considering only the discrete cases of perfect competition, Cournot-Nash and monopoly, that is, restricting attention to $\theta^S = \{0, \frac{1}{n}, 1\}$—showing, for example, that, all else equal, cost pass-through under Cournot-Nash may be lower than under monopoly where the latter lies below 1.

It is useful to consider a couple of examples in which pass-through is less than 1 and the condition of Proposition 1 is met. Suppose that demand is convex but log-concave, $\xi^D \in [0, 1]$, and that costs are at least as convex as a quadratic cost function, $C(x_i) \propto x_i^2$; in such cases, Proposition 1 always holds for pass-through $\rho|_{\tau \to 0}$ of a small new tax, as then $\eta^S \geq 1$. The required degree of cost convexity can be given a microfoundation based on a standard Cobb-Douglas technology. Let $x_i = Ak_i^\alpha l_i^\beta$ be firm i's production technology for output, where k_i is factor of production, say capital, that is fixed (e.g., in the short run) while l_i is a flexible factor, say labour, and A, α, $\beta > 0$ are parameters. Taking factor prices as given, firm i's optimal cost function $C_i(x_i; k_i)$ is at least as convex as a quadratic whenever $\beta \leq \frac{1}{2}$. A larger endowment of the fixed factor k_i reduces marginal cost but leaves the cost elasticity $\eta^S = (1-\beta)/\beta$ unchanged. These kinds of quadratic cost functions (with $\alpha = \beta = \frac{1}{2}$) are frequently used in the literature on merger analysis (McAfee & Williams 1992). Of course, they also underlie textbook expositions of perfect competition with linear demand and a linearly upward-sloping supply curve.

To see another example, consider the marginal-cost function with a "soft" capacity constraint given by $C'(x_i) = c + \max\{0, \lambda(x_i - K)\}$ where $\lambda > 0$ is a parameter and K is firm i's installed capacity. While it is possible for production to exceed capacity, $x_i > K$, this becomes increasingly costly as a strain on resources. If so, for a small new tax $\tau \to 0$, cost convexity is $\eta^S = \lambda(x_i/K)/[c + \lambda(x_i/K - 1)]$ and so $\eta^S \geq 1$ holds whenever the cost-convexity effect dominates with $\lambda \geq c$. More generally, the condition from Proposition 1 always holds for a sufficiently large (but finite) η^S, regardless of demand conditions and competitive intensity.

By contrast, existing literature on pass-through under imperfect competition typically assumes that marginal costs are constant, $\eta^S = 0$. Then the standard intuition obtains whenever demand is log-concave, $\xi^D \leq 1$. Conversely, if the condition from Proposition 1 holds with $\xi^D \geq 1$, *both* markets feature pass-through in excess of 1—but it is closer to 1 in the more competitive market, $\rho(\theta_2^S) \geq \rho(\theta_1^S) \geq 1$. A familiar example occurs with Cournot competition and a highly convex demand curve with constant elasticity ($\xi^D = 1 + 1/\varepsilon^D$) for which the equilibrium price-cost margin $(p - \widehat{C}')/p = \theta^S/\varepsilon^D$ is constant—so that cost pass-through $\rho = \varepsilon^D/(\varepsilon^D - \theta^S)$ always exceeds 1. This paper instead focuses on the "normal" case of pass-through that lies below 1. The main point is that, with non-constant marginal cost, $\eta^S > 0$, more competition can yield lower pass-through even when it always lies below 1. A related observation is that the condition from Proposition 1 that the cost elasticity satisfies $\eta^S \geq 1 - \xi^D$

is also equivalent to the *level* of cost pass-through in market j being bounded above according to $\rho(\theta_j^S) \leq [1 + (1 - \xi^D)\varepsilon^D]^{-1}$ (for $j = 1, 2$).

To get a sense of numbers on the demand side, the range $\xi^D \in [0, 1]$ is satisfied by three of the four demand specifications in the influential study of oligopolistic competition by Genesove & Mullin (1998): linear ($\xi^D = 0$), quadratic ($\xi^D = \frac{1}{2}$) and exponential ($\xi^D = 1$) demand.[12] In the macroeconomics literature, Gopinath & Itskhoki (2011) calibrate a model of monopolistic competition and, as baseline parameters, use a demand elasticity $\varepsilon^D = 5$ and with a superelasticity $\psi^D = 6$; taken together, these imply that demand curvature $\xi^D = 0$, that is, demand is (locally) exactly linear. On the empirical side, Beck & Lein (2019) estimate a discrete choice model based on a homescanner dataset of a large number of consumer goods. They find that the demand elasticity ε^D ranges between 3 to 5 while the superelasticity ψ^D ranges between 1 to 2. This, in turn, converts into a surprisingly tight range of demand curvatures: $\xi^D \in [\frac{2}{3}, 1]$.

Taken together, and acknowledging the differences in methodologies, this combination of theoretical and empirical considerations suggests that demand being convex but log-concave, $\xi^D \in [0, 1]$ will, in many cases, be a plausible baseline assumption on demand curvature. This has three implications for whether market power can increase pass-through: (i) cost convexity is a (weakly) necessary condition, (ii) a modest degree of cost convexity can be sufficient, and (iii) a (grossly) sufficient condition is that cost convexity satisfies $\eta^S \geq 1$—which is met by cost curves that are at least quadratic.

What is driving the result from Proposition 1? Recall from Lemma 1 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 2. *Equilibrium cost pass-through satisfies:*

$$\frac{\partial}{\partial\theta^S}\left[\frac{\partial\rho}{\partial\eta^S}\right]_{\varepsilon^D, \xi^D \text{ fixed}} \geq 0$$

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

Lemma 2 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 then more strongly so for a more competitive market. This helps explain why, in markets with a fairly inflexible production technology, more competition can be associated with less pass-through.[13]

[12] Their fourth specification is constant-elasticity demand for which the condition from Proposition 1 is always met but pass-through exceeds 1.

[13] The supermodularity property cannot hold globally because pass-through $\rho \to 0$ as inflexibility $\eta^S \to \infty$ regardless of intensity of competition.

Through the lens of incidence analysis, these results highlight the role of the producer surplus generated by a competitive market. In the "normal" case with pass-through below 1, cost convexity is necessary for Proposition 1 to apply; this, in turn, means that the producer surplus associated with a competitive market is non-zero. By contrast, recent literature that employs pass-through as a tool for incidence analysis often makes assumptions—specifically constant marginal cost and firm symmetry—that imply that a competitive industry always makes zero profits.

5 Pass-through "within market"

Now consider the second approach: in the same market, with given demand and cost functions, competition (exogenously) intensifies as measured by a lower value of θ^S. How does more competition affect pass-through $\rho(\theta^S)$?

This analysis now takes into account knock-on effects on the equilibrium values of $(\varepsilon^D, \xi^D, \eta^S)$ that arise from the induced changes to the market price and firm-level output. In particular, it follows immediately from Lemma 1 that equilibrium cost pass-through is lower with more competition, that is, $\frac{d\rho(\theta^S)}{d\theta^S} \geq 0$, if and only if:

$$\eta^S \left(1 - \frac{d\varepsilon^D}{d\theta^S}\right) \geq (\varepsilon^D - \theta^S)\frac{d\eta^S}{d\theta^S} + \frac{d}{d\theta^S}\left[\theta^S(1-\xi^D)\right]. \tag{3}$$

Unlike in the previous between-markets approach, these knock-on effects may now depend on whether the change to θ^S is due to a change in conduct θ or in the number of rivals n. A preliminary result brings these onto a like-for-like basis as drivers of $d\theta^S$ by comparing, for example, the price change due to softer conduct as $\frac{dp}{d\theta^S}\big|_{d\theta} = \frac{dp}{d\theta}\left[\frac{1}{d\theta^S/d\theta}\right]$ with that due to fewer firms $\frac{dp}{d\theta^S}\big|_{dn} = \frac{dp}{dn}\left[\frac{1}{d\theta^S/dn}\right]$:

Lemma 3. *(a) Softer conduct decreases equilibrium per-firm output and increases the equilibrium market price according to:*

$$\left.\frac{dx}{d\theta^S}\right|_{d\theta} = -\rho x < 0 \text{ and } \left.\frac{dp}{d\theta^S}\right|_{d\theta} = \left[-p'(X)X\right]\rho > 0.$$

(b) Fewer firms increases equilibrium per-firm output and increases the equilibrium market price according to:

$$\left.\frac{dx}{d\theta^S}\right|_{dn} = \frac{(1-\theta^S\xi^D)}{\theta^S}\rho x > 0 \text{ and } \left.\frac{dp}{d\theta^S}\right|_{dn} = \left[-p'(X)X\right]\rho\left[1 + \eta^S\frac{(\varepsilon^D - \theta^S)}{\theta^S}\right] > 0.$$

Higher market power unambiguously increases the market price, regardless of whether it is due to softer conduct (higher θ) or a less concentrated market structure (lower n). In the familiar case with constant marginal cost ($\eta^S = 0$), the induced price increase is identical. With increasing marginal cost ($\eta^S > 0$), however, the market price increases more strongly due to fewer firms.

The reason stems from an asymmetry in how these two changes in market power affect firm-level output. Softer conduct leads to lower industry output and—as the number of firms remains fixed—also to lower firm-level output. Higher concentration also reduces industry output but—due to the reduction in the number of firms—leads to *higher* firm-level output for the remaining firms.[14] With convex costs, the latter leads to relatively higher equilibrium marginal cost—and hence to an additional source of upward pressure on price.[15]

Given the differences in output and price responses, the three knock-on effects on the equilibrium values of $(\varepsilon^D, \xi^D, \eta^S)$ will vary between competitive conduct and market structure as sources of market power. Lemma 3 implies that the knock-on effects will have the same sign for (ε^D, ξ^D) as these both depend on the price impact while the knock-on effect on η^S will have a different sign given the opposite impacts on firm-level output.

The next result uses Lemma 3 to provide necessary and sufficient conditions under which—contrary to standard intuition—a small increase in competition, $d\theta^S < 0$, leads to weaker pass-through in the same market.

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 $x_i = x$, will again be identical across firms with $\phi_i^S = \phi^S$ (also recalling that $\widehat{C}''(\cdot) = C''(\cdot)$ and $\widehat{C}'''(\cdot) = C'''(\cdot)$). The relationship between the elasticity of marginal cost η^S and the elasticity of its slope is given by $\eta^S = [(\phi^S + 1) - \zeta^S]$ where $\zeta_i^S \equiv (d\eta^S/dx_i)(x_i/\eta^S)$ is the superelasticity of marginal cost and again $\zeta_i^S = \zeta^S$ given symmetry.

Proposition 2. *(a) Equilibrium cost pass-through is lower with softer conduct,* $\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{d\theta} \geq 0$, *if and only if:*

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

which holds if the elasticities of marginal cost η^S *and of the slope of marginal cost* ϕ^S *are sufficiently large. Equilibrium cost pass-through* $\rho(\theta^S) \leq 1$, *and is lower with more competition,* $\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{d\theta} \geq 0$, *if demand is log-concave* $\xi^D \leq 1$ *and its curvature is non-decreasing* $\frac{d\xi^D}{dp} \geq 0$ *as well as:*

$$\eta^S + \xi^D \geq 1 \text{ and } \phi^S + \xi^D \geq \frac{\left[1 + (1 - \xi^D)\varepsilon^D\right]}{(\varepsilon^D - \theta^S)}.$$

[14]This is a classic oligopoly-theory result, see, e.g., Vives (2000, Chapter 4).

[15]This effect corresponds to the industry supply curve in a competitive market getting shallower as more firms are added to the market, so that cost constraints at the firm-level are relaxed as each individual firm shrinks in size. Some models sidestep this feature by instead assuming a marginal-cost function with a multiplicative form $C_i'(nx_i)$ to obtain an upward-sloping competitive supply curve that does not depend on the number of firms (e.g., Newbery & Greve 2017).

(b) Equilibrium cost pass-through is lower with fewer firms $\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{dn} \geq 0$*, if and only if:*

$$-\frac{\eta^S(\varepsilon^D-\theta^S)}{[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)]}\left[\eta^S\left(\frac{(1-\theta^S)+(1-\xi^D)\varepsilon^D}{\theta^S}\right)\right.$$
$$\left.+(1-\xi^D)+\zeta^S\frac{(1-\theta^S\xi^D)}{\theta^S}\right] \quad \geq \quad \frac{d}{d\theta^S}\left[\theta^S(1-\xi^D)\right]$$

which holds if the elasticity of marginal cost $\eta^S > 0$ *while the superelasticity of marginal cost* ζ^S *is sufficiently negative. Equilibrium cost pass-through* $\rho(\theta^S) \leq 1$*, and is lower with more competition,* $\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{dn} \geq 0$*, if demand is convex but log-concave* $\xi^D \in [0,1]$ *and its curvature is non-decreasing* $\frac{d\xi^D}{dp} \geq 0$ *and the elasticity of marginal cost satisfies* $\eta^S \in (0,1]$ *as well as:*

$$-\zeta^S \geq \varepsilon^D + (1+\theta^S)\left[1+\frac{\theta^S}{\eta^S(\varepsilon^D-\theta^S)}\right].$$

Overall, Proposition 2 delivers a similar conclusion to Proposition 1: Under plausible conditions, it is also possible for more competition to reduce "within market" pass-through.

Part (a) of the result speaks to higher market power that stems from softer conduct among firms. To get a sense for the required degree of cost convexity for the necessary and sufficient condition, consider the case in which demand is linear where $\left[\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{d\theta}\right]_{\xi^D=0} \geq 0 \Leftrightarrow \eta^S(\phi^S-1) \geq (1+\theta^S)/(\varepsilon^D-\theta^S)$. If five firms initially play Cournot-Nash and the initial price elasticity of demand is two ($n=5, \theta=1, \varepsilon^D=2$), then greater competitive intensity reduces pass-through as long as $\eta^S(\phi^S-1) \geq \frac{2}{3}$.[16] More generally, the condition is more likely to be met if demand is more elastic (higher ε^D) and more convex (higher ξ^D) and marginal cost is more convex (higher η^S) and its slope is more convex (higher ϕ^S).

It is useful to see a couple of examples of cost constraints that satisfy these properties. First, suppose again that cost functions are short-run Cobb-Douglas $C(x_i) = \delta x_i^\mu$ with parameters $\delta > 0$, $\mu > 1$. If the cost shifter is initially zero, $\tau = 0$, then cost elasticities follow as $\eta^S = \mu - 1, \phi^S = \mu - 2$ and the above condition for the linear-demand quintopoly becomes $\mu \geq 3.29$. This condition is tighter than Proposition 1—which here would be $\mu \geq 2$. The reason is that softer conduct leads to a higher price elasticity of demand, $\left.\frac{d\varepsilon^D}{d\theta^S}\right|_{d\theta} > 0$ (via a higher price)—which pushes pass-through down (precisely whenever $\eta^S > 0$, by Lemma 1).[17]

Second, consider the marginal-cost function $C(x_i; K) = [cx_i - \omega \ln(1 - x_i/K)]$, where $\omega > 0$ is a parameter and $\kappa_i \equiv x_i/K \in [0,1]$ is the rate of capacity utilization (where each firm has installed capacity K). This formulation has been a useful modelling device to approximate "hard" capacity constraints in resource-intensive markets like the production of natural gas

[16] Similar to Proposition 1, the condition is equivalent to the *level* of cost pass-through being sufficiently low—because of cost convexity (Lemma 1)—with $\rho \leq [(\phi^S-1)/\phi^S]/(1+\theta^S)$.

[17] In this example with Cobb-Douglas costs and linear demand the third-order effects on costs and demand are both zero, $d\eta^S/d\theta^S = 0 = d\xi^D/d\theta^S$.

(e.g., Golombek, Gjelsvik & Rosendahl 1995). Here $\eta^S, \phi^S \to \infty$ as the capacity constraint is reached, $\kappa_i \to 1$, so the condition is always met if firms are sufficiently close to capacity. For example, if c and τ are small relative to ω then $\eta^S \approx \kappa_i/(1-\kappa_i) = \frac{1}{2}\phi^S$ and the condition for the standard intuition to be overturned in the linear-demand quintopoly is that capacity utilization exceeds 47%.[18]

Part (a) also gives a simple set of sufficient conditions that apply to the "normal" case where pass-through is less than 1. First, demand is log-concave $\xi^D \leq 1$ and is more convex at a higher price $d\xi^D/dp \geq 0$; the latter condition applies to any demand curve that belongs to the family $p(X) = \alpha - \beta X^\gamma$, with parameters $\alpha > 0, \beta > 0, \gamma \geq 0$), for which curvature $\xi^D = 1 - \gamma$ is constant (so $d\xi^D/dp = 0$). This demand family corresponds to (i) the ratio of the slopes of inverse demand and marginal revenue being constant under monopoly (Bulow & Pfleiderer 1983), (ii) the direct demand function $D(p)$ satisfying a generalized concept of convexity known as "rho-linearity" (Caplin & Nalebuff 1991; Anderson & Renault 2003), and (iii) consumer valuations being drawn from a generalized Pareto distribution (Bulow & Klemperer 2012). Examples for which $d\xi^D/dp > 0$ (and $\xi^D \leq 1$) include Gaussian and logistic demand curves (Fabinger & Weyl 2018, Appendix J).

Second, firms' costs are sufficiently convex: they satisfy the condition from Proposition 1, $\eta^S + \xi^D \geq 1$, and the elasticity of the slope of marginal cost $\phi^S > 0$ is also large enough. Equivalently, recalling that $\phi^S = \eta^S - 1 + \zeta^S$, the superelasticity of marginal cost is sufficiently high with $\zeta^S \geq [1 + (1-\xi^D)\varepsilon^D]/(\varepsilon^D - \theta^S) > 0$. This is consistent with the notion that production inflexibility also becomes significantly more acute at higher output levels; then softer conduct reduces firm-level sales ($\frac{dx}{d\theta^S}\big|_{d\theta} < 0$, by Lemma 3) so that cost convexity is relaxed (as $\frac{d\eta^S}{d\theta^S}\Big|_{d\theta} = \frac{d\eta^S}{dx}\frac{dx}{d\theta^S}\big|_{d\theta} < 0$ where $\frac{d\eta^S}{dx} > 0 \Leftrightarrow \zeta^S > 0$)—which pushes cost pass-through upwards (Lemma 1). These conditions ensure that the cost-elasticity effect $\frac{d\eta^S}{d\theta^S}\Big|_{d\theta}$ and the demand-curvature effect $\frac{d\xi^D}{d\theta^S}\Big|_{d\theta}$ together outweigh the demand-elasticity effect $\frac{d\varepsilon^D}{d\theta^S}\Big|_{d\theta}$ that works in favour of the standard intuition.

Part (b) speaks to higher market power that stems from a more concentrated industry with fewer firms. While the standard intuition is again overturned for a range of parameter values, the underlying conditions seem less natural than those from part (a).

The main reason is that the demand-elasticity effect $d\varepsilon^D/d\theta^S > 0$ that works in favour of the standard intuition (at least with log–concave demand) is now more pronounced. All else equal, the increase in the market price due to fewer firms is stronger than due to softer conduct (whenever $\eta^S > 0$, by Lemma 3). So the price elasticity of demand also increases more strongly—which pushes cost pass-through downwards (whenever $\eta^S > 0$, by Lemma 1).

[18] For this cost function, the elasticity of marginal cost can be written as $\eta^S = \frac{\kappa_i}{(1-\kappa_i)}\left[\frac{\omega}{\omega + (1-\kappa_i)(c+\tau)}\right] > 0$ while the elasticity of its slope $\phi^S = \frac{2\kappa_i}{(1-\kappa_i)} > 0$. If c and τ are small relative to ω then $\eta^S \approx \kappa_i/(1-\kappa_i)$ and so the condition $\eta^S(\phi^S - 1) \geq \frac{2}{3}$ becomes (approximately) $\frac{\kappa_i(3\kappa_i - 1)}{(1-\kappa_i)^2} \geq \frac{2}{3}$ which corresponds to $\kappa_i \geq .47$.

This additional force turns out to be sufficiently strong that for a log-concave demand curve now always $\left.\frac{d\varepsilon^D}{d\theta^S}\right|_{dn} \geq 1$. To overturn the standard intuition, the necessary and sufficient condition in part (b) therefore relies on the two third-order effects—the cost-elasticity effect $d\eta^S/d\theta^S$ and the demand-curvature effect $d\xi^D/d\theta^S$—being sufficiently favourable. Put differently, if $\xi^D \leq 1$ and $d\eta^S/d\theta^S = 0 = d\xi^D/d\theta^S$ then the standard intuition always obtains. Moreover, while $\eta^S > 0$ is necessary to overturn the standard intuition, high values of η^S often now work in its favour, unlike in part (a).

The demand-curvature effect $\left.\frac{d\xi^D}{d\theta^S}\right|_{dn}$ takes the same sign as with softer conduct in part (a), and again works against the standard intuition where demand is more convex at a higher price $d\xi^D/dp \geq 0$. However, it is also more pronounced, all else equal, because of the stronger increase in the market price with fewer firms (whenever $\eta^S > 0$, by Lemma 3).

The cost-elasticity effect $\left.\frac{d\eta^S}{d\theta^S}\right|_{dn}$ is again zero with a short-run Cobb-Douglas cost function and a small tax ($\tau \to 0$) for which the superelasticity of marginal cost $\zeta^S = 0$, and can go either way in general. However, it takes on the opposite sign to that under softer conduct because a more concentrated market structure instead leads to *higher* firm-level sales ($\left.\frac{dx}{d\theta^S}\right|_{dn} > 0$, by Lemma 3). So this effect now works against the standard intuition in cases where the superelasticity is *negative*, $\zeta^S < 0$.

To get a sense for the condition of part (b), suppose that demand is linear, $\xi^D = 0$, and that $\eta^S = 1$ (so the condition of Proposition 1 is just met); this brings the further simplification that the superelasticity of marginal cost and the elasticity of the slope of marginal cost now coincide, $\zeta^S = \phi^S$. The condition then is $\left[\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{dn}\right]_{\xi^D=0,\eta^S=1} \geq 0 \Leftrightarrow -\zeta^S \geq \varepsilon^D(1+\varepsilon^D)/(\varepsilon^D - \theta^S)$ so that ζ^S must be sufficiently negative. For the linear-demand Cournot quintopoly with $n = 5, \theta = 1, \varepsilon^D = 2$, this becomes $\zeta^S \leq -\frac{10}{3}$. So here the standard intuition is overturned if costs are moderately *convex* while marginal costs are sufficiently *concave*.

Part (b) also gives a set of sufficient conditions for the "normal" case where pass-through is less than 1. It invokes the previous baseline assumption that demand is convex but log-concave $\xi^D \in [0, 1]$ and also requires that marginal cost is increasing—but not too much, with $\eta^S \in (0, 1]$. (In the case with $\xi^D = 0$ and $\eta^S = 1$, the sufficient condition coincides with the necessary condition.) For example, if again $n = 5, \theta = 1, \varepsilon^D = 2$ and $\xi^D = 0$ but now $\eta^S = \frac{1}{2}$ then the sufficient condition $\zeta^S \leq -\frac{52}{15}$ is mildly tighter than before—while the condition of Proposition 1 is *not* satisfied here.

To see some bottom-up numbers, consider the cubic cost function $\widehat{C}(x) = (c+\tau)x + \frac{a}{2}x^2 + \frac{b}{6}x^3$, with parameters $a, c > 0$ and $b < 0$. Its marginal-cost elasticity $\left.\eta^S\right|_{\tau=0} > 0$ is positive subject to $[a + bx] > 0$ but also satisfies $\left.\eta^S\right|_{\tau=0} \leq 1 \Leftrightarrow bx^2 \leq 2c$ while the elasticity of the slope of marginal cost $\phi^S < -1 \Leftrightarrow bx < -\frac{a}{2}$ which is met if the parameter b is sufficiently negative (but still $bx > -a$).[19] Now suppose that output $x = 1$ (by appropriate choice of the demand

[19]For this cost function, $\eta^S = \frac{x[a+bx]}{(c+\tau)+x\left[a+\frac{b}{2}x\right]} > 0$ while $\phi^S = \frac{bx}{[a+bx]} \gtreqless 0$.

function) while the cost parameters $a = 1$ and $c = 0$. Then $\eta^S\big|_{\tau=0} = \frac{[1+b]}{(1+b/2)} \in (0,1)$ and $\phi^S = \frac{b}{[1+b]} < 0$ while $-b \in (\frac{1}{2}, 1)$ is also required. In particular, as $b \to -1$, $\eta^S\big|_{\tau=0} \to 0$ and $\phi^S \to -\infty$ so the superelasticity $\zeta^S \to -\infty$ (recalling that $\zeta^S = 1 + \phi^S - \eta^S$)—and so the conditions of part (b) are always met in the limit. The requirements, however, are quite tight: for example, if instead $b \geq -\frac{3}{4}$, then $\eta^S\big|_{\tau=0} \geq \frac{2}{5}$, $\phi^S \geq -3$ and $\zeta^S \geq -2\frac{2}{5}$ and so the sufficient condition is then *not* met in the example with $\varepsilon^D = 2$.

In sum, Proposition 1's "between markets" condition $\eta^S + \xi^D \geq 1$ is neither necessary nor sufficient for the "within market" results of Proposition 2 to hold. Thereby the conditions for Proposition 2 are often tighter due to the demand-elasticity effect that pushes pass-through downwards when $\eta^S > 0$. Nonetheless, due to higher-order properties of demand and cost functions, there are instances where the conditions of Proposition 2(a) or 2(b) are met where those of Proposition 1 are not. Unlike in commonly-analyzed models with constant marginal cost, the detailed source of market power is important for the analysis of changes in pass-through when $\eta^S > 0$; the conditions for the standard intuition to be overturned generally seem more natural for softer conduct than for fewer firms.

For a *discrete* increase in market power from, say, θ_1^S to θ_2^S (where $\theta_2^S > \theta_1^S$), if either of the conditions from Proposition 2(a) or 2(b) holds over the range $\theta^S \in [\theta_1^S, \theta_2^S]$, then this is sufficient (but not necessary) to conclude that $\rho(\theta_2^S) = \rho(\theta_1^S) + \int_{\theta_1^S}^{\theta_1^S} \rho'(\theta^S)d\theta^S > \rho(\theta_1^S)$. To illustrate, consider a market with a single firm and linear demand curve ($n = 1$,$\xi^D = 0$) with slope $p' = -\beta$. Suppose that the firm is initially a price-taker ($\theta_1^S = 0$) and then becomes a monopolist ($\theta_2^S = 1$). 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:

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

which holds if and only if $\int_{x^m}^{x^c} C'''(y)dy = [C''(x^c) - C''(x^m)] \geq \beta$.[20] So competition reduces pass-through if $C''(\cdot) > 0$, and $C'''(\cdot)$ is large enough. The result of Figure 1, with $\rho^m = \frac{1}{2} > 0 = \rho^c$, is nested where $C''(x^m) = 0 \Leftrightarrow \eta^S(x^m) = 0$ (as marginal cost is constant at c around the monopoly output) and $C''(x^c) \to \infty \Leftrightarrow \eta^S(x^c) \to \infty$ (as the competitive industry produces at capacity K).[21,22]

[20]The relationship $\eta^S(\varepsilon^D - \theta^S) = C''(\cdot)/[-p'(\cdot)]$ (with $n = 1$) from the proof of Lemma 1 here presentationally simplifies the comparison.

[21]Strictly speaking, this involves a non-differentiability of the cost function around the capacity constraint K. However, Figure 1 can be closely approximated using the cost function $C(x; K) = [cx - \omega\ln(1 - x/K)]$, where $\omega > 0$ is small so that $\eta^S \approx 0$ for $x^m/K < 1$ but also $\eta^S \to \infty$ as $x^c/K \to 1$. Economic theory typically assumes that cost functions are differentiable as an approximation to what in practice may be "kinked" cost schedules (Kahn 1989; Marcuzzo 1994). The present results on pass-through and market power can obtain also with such kinked cost functions—as in Figure 1—as long as the cost jumps occur in the relevant region of production.

[22]In Figure 1, perfect competition produces higher social welfare than monopoly even though it features lower

6 Price competition and differentiated products

The analysis so far has relied on a Cournot-style model with homogenous products that nests perfect competition as a special case. This section shows that its main insights about pass-through and market power also apply under price competition with differentiated products.

Consider a model of Bertrand competition with n symmetric firms that each sell a variant of a differentiated product at price p_i. Firm i's demand is $D_i(\mathbf{p}) = D(p_i, p_{-i})$ where p_{-i} captures the prices set by its rivals. Demand is downward-sloping, $\frac{\partial D_i}{\partial p_i} < 0$, and products are gross substitutes, $\frac{\partial D_i}{\partial p_j} > 0$ (for all $j \neq i$). When all firms set the same price, with $p_i = p$ (for all i), demands are symmetrically $D_i = D(p)$ (for all i) and so aggregate demand is $\sum_{j=1}^{n} D_i = nD(p)$.

Three elasticity measures will prove useful, all evaluated at symmetric prices. First, let $\varepsilon^d \equiv -\frac{\partial D}{\partial p_i}\frac{p}{D_i} > 0$ be the firm-level price elasticity of demand. Second, a market-wide increase in prices leads to lower demand, $\frac{\partial D}{\partial p} = \frac{\partial D}{\partial p_i} + \sum_{j\neq i}\frac{\partial D}{\partial p_j} < 0$ so let $\varepsilon^D \equiv -\frac{\partial D}{\partial p}\frac{p}{D} > 0$ which is then equal to the market-level price elasticity of demand (with $\varepsilon^D < \varepsilon^d$). Third, define a measure of demand curvature as $\varepsilon^m \equiv -\, p\frac{\partial}{\partial p}\left(\frac{\partial D}{\partial p_i}\right)\Big/\frac{\partial D}{\partial p_i}$. Demand is convex in prices if $\varepsilon^m \geq 0$ and concave otherwise. A well-behaved Bertrand-Nash equilibrium requires that $(\varepsilon^d + \varepsilon^D - \varepsilon^m) > 0$, so demand again cannot be too convex (Anderson, de Palma & Kreider 2001).

Firm i's profits are $\Pi_i = p_i D_i(\mathbf{p}) - \widehat{C}(D_i)$ and its first-order condition is $(p_i - \widehat{C}')\frac{\partial D}{\partial p_i} + D = 0$. At symmetric equilibrium, the elasticity-adjusted Lerner index is $L \equiv \varepsilon^D(p - \widehat{C})/p = \varepsilon^D/\varepsilon^d \in (0,1)$, where $\varepsilon^d > 1$. The aggregate diversion ratio $R \equiv -\left[\sum_{j\neq i}\frac{\partial D_i}{\partial p_j}\Big/\frac{\partial D_i}{\partial p_i}\right] \in (0,1)$ is a proximate measure of the intensity of competition (Shapiro 1996; Weyl & Fabinger 2013) such that $L = [1 - R]$. For a given value of ε^D, stronger diversion between products (higher R) corresponds directly to a greater firm-level price elasticity (higher ε^d and lower L).

Lemma 4. *The equilibrium rate of cost pass-through under differentiated Bertrand competition equals:*

$$\rho(\varepsilon^d, \varepsilon^D, \varepsilon^m, \eta^S) = \frac{\varepsilon^d}{[(\varepsilon^d + \varepsilon^D - \varepsilon^m) + \eta^S(\varepsilon^d - 1)\varepsilon^D]} > 0.$$

Lemma 4 generalizes a pass-through result in Anderson, de Palma & Kreider (2001) to allow for non-constant marginal cost. There are two immediate similarities with generalized Cournot competition. First, all else equal, greater cost constraints weaken pass-through, $\partial\rho/\partial\eta^S < 0$. Second, the "normal" case in which pass-through is less than 1 holds, for any cost elasticity $\eta^S \geq 0$, if demand is not too convex in the sense that its (normalized) demand curvature $E^D \equiv \varepsilon^m/\varepsilon^D \leq 1$.

This Bertrand pass-through formula directly mirrors that for generalized Cournot. To see

pass-through. This shows that the relationship between pass-through and social welfare is complex and that any inference on the extent of market power needs to take in account the details of firms' cost conditions.

this, using $E^D \equiv \varepsilon^m/\varepsilon^D$ and $L = \varepsilon^D/\varepsilon^d = [1-R]$, the formula can also be written as:

$$\rho(\varepsilon^D, E^D, \eta^S; L) = \frac{1}{[1 + (1-E^D)L + \eta^S(\varepsilon^D - L)]} > 0 \tag{4}$$

thus corresponding directly with Lemma 1 where $L = [1-R]$ under Bertrand while $L = \theta^S$ under Cournot (and demand curvature E^D under symmetric product differentiation is replaced by ξ^D with homogenous products).

Varying competition between markets

What is the impact of market power on pass-through? Begin with the "between markets" approach that compares two markets, 1 and 2, on an otherwise like-for-like basis—by Lemma 4, here with the same values of $(\varepsilon^D, E^D, \eta^S)$. The two markets differ only in that market 1 is more competitive: individual firms have less pricing power, with $\varepsilon_1^d > \varepsilon_2^d$; equivalently, given an identical ε^D, market 1 has a lower elasticity-adjusted Lernex and a higher aggregate diversion ratio, with $R_1 > R_2$.

Proposition 3. *Under differentiated Bertrand competition, equilibrium cost pass-through is lower in the more competitive market, $\rho(R_1) \leq \rho(R_2)$, if and only if demand and cost conditions satisfy $\eta^S + E^D \geq 1$.*

Just like Proposition 1 for Cournot-style markets, the standard intuition is always overturned also under differentiated Bertrand competition if cost convexity sufficiently pronounced. Where demand is linear or convex but cost pass-through remains below 1, with $E^D \in [0,1]$, the condition boils down to a modest degree of cost convexity. With linear demands, it is again met for cost functions that are at least quadratic (for small τ); a logit demand system can be locally concave or convex (at symmetric equilibrium) but always satisfies $E^D \leq 1$ so that cost convexity with $\eta^S > 0$ is necessary to overturn the standard intuition.

Varying competition within a market

Now consider an increase in competition within a single market. Cleanly implementing this approach requires a comparative static on an exogenous measure of market power. Natural candidates are the degree of product substitutability and the number of firms (see also Vives 2008). In general, this exercise is more subtle under differentiated Bertrand competition as such changes in market power may alter the product offering available to consumers—and so often directly affect the structure of the demand system $D_i(\mathbf{p})$.[23]

To illustrate the similarities with the previous Cournot analysis, consider the Shubik-Levitan linear demand system $D_i(\mathbf{p}) = \frac{1}{n}\left[\alpha - \beta\left(p_i - \gamma\left(\overline{p} - p_i\right)\right)\right]$, where $\overline{p} \equiv \frac{1}{n}\sum_{j=1}^n p_j$ is the average

[23]By contrast, in the previous Cournot-style model, the demand curve $p(X)$ and the conduct parameter θ^S have no direct dependence on one another.

price, $\alpha, \beta, \gamma > 0$ are parameters, and higher values of γ represent stronger product substitutability (Shubik & Levitan 1980; Choné & Linnemer 2020).[24] First, this system has the feature that, at symmetric prices, aggregate demand $\sum_{j=1}^{n} D_i = nD(p) = \alpha - \beta p$ does not directly depend on the number of different products on offer; in this sense, the system retains comparability with Cournot-style models. Second, using Lemma 4, cost pass-through $\rho = \frac{1}{\left[[2-R(\gamma,n)]+\frac{\beta}{n}C''\right]} \in (0,1)$ yields the "normal" case.[25]

The precise source of market power can matter for "within market" comparative statics. The aggregate diversion ratio $R(\gamma, n = \gamma(n-1)/[n+\gamma(n-1)] \in (0,1)$ increases with the number of firms n and with the substitution parameter γ—where the latter plays a similar role to competitive conduct in a Cournot-style model. A preliminary result again brings these onto a like-for-like basis by comparing, for example, the price change due to stronger differentiation as $\frac{dp}{dR}\Big|_{d\gamma} = \frac{dp}{d\gamma}\left[\frac{1}{\frac{dR}{d\gamma}}\right]$ with that due to fewer firms $\frac{dp}{dR}\Big|_{dn} = \frac{dp}{dn}\left[\frac{1}{\frac{dR}{dn}}\right]$:

Lemma 5. *Under Bertrand competition with a Shubik-Levitan linear demand system:*
(a) Higher product substitutability reduces the symmetric equilibrium price and increases per-firm sales according to:

$$\frac{dp}{dR}\bigg|_{d\gamma} = -\frac{n}{\beta}\rho D_i < 0 \ \textit{and}\ \frac{dD_i}{dR}\bigg|_{d\gamma} = \rho D_i > 0.$$

(b) A larger number of firms reduces the symmetric equilibrium price and decreases per-firm sales according to:

$$\frac{dp}{dR}\bigg|_{dn} = -\frac{n}{\beta}\left[1+\frac{\frac{\beta}{n}C''}{n\frac{dR}{dn}}\right]\rho D_i < 0 \ \textit{and}\ \frac{dD_i}{dR}\bigg|_{dn} = -\left[\frac{[2-R]}{n\frac{dR}{dn}} - 1\right]\rho D_i < 0.$$

These results with differentiated products correspond directly to those of Lemma 3 for Cournot-style competition for the case of linear demand. For per-firm sales, there is an asymmetry between conduct and structure: they rise with weaker product differentiation but decline with a larger number of firms. By contrast, less market power unambiguously reduces the market price: With constant marginal cost ($\eta^S = 0 \Leftrightarrow C'' = 0$), the induced price increase is identical; with increasing marginal cost ($\eta^S > 0 \Leftrightarrow C'' > 0$), the price falls more strongly due to fewer firms as cost convexity is relaxed with the smaller firm size.[26,27]

[24] A sufficient condition for interior equilibrium is that $\alpha/\beta > \widehat{C}'(0) = C'(0) + \tau$.

[25] From the proof of Lemma 4, $\eta^S(\varepsilon^D - [1-R]) = -C''\frac{\partial D_i}{\partial p} = \frac{\beta}{n}C''$.

[26] These comparative-statics results are well-known for Shubik-Levitan demand with constant marginal costs (e.g., Vives 2008); Lemma 5 shows that they carry over to situations with cost constraints.

[27] While the detailed expressions of Lemma 5(b), especially, may superficially look different from those in Lemma 3(b), they are in fact directly analogous. Note that $[-p'(X)X]$ under linear Cournot plays the same role as $\frac{n}{\beta}D_i = -\frac{\partial D_i}{\partial p}D_i$ under a linear Shubik-Levitan demand system, and recall that the Lerner indices under Cournot and Bertrand relate as $\theta^S(\theta, n) = [1 - R(\gamma, n)]$ so that $d\theta^S = -dR$ and also $\frac{d\theta}{dn} = -\frac{\theta^S}{n} = \frac{dR}{dn}$. Hence the price changes relate are directly analogous, recalling that $\frac{\beta}{n}C'' = \eta^S(\varepsilon^D - \theta^S) = \eta^S(\varepsilon^D - [1-R])$ and noting

Proposition 4. *Under Bertrand competition with a Shubik-Levitan linear demand system:*
(a) Equilibrium cost pass-through is lower with higher product substitutability, $\frac{d\rho}{dR}\Big|_{d\gamma} \leq 0$*, if and only if:*

$$\frac{\beta}{n} C''(\phi^S - 1) \geq [2 - R];$$

(b) Equilibrium cost pass-through is lower with more firms, $\frac{d\rho}{dR}\Big|_{dn} \leq 0$*, if and only if:*

$$-\frac{\beta}{n} C'' \left(\frac{\left[[2-R] - n\frac{dR}{dn}\right]}{\left[[2-R] + \frac{\beta}{n} C''\right]} \phi^S + 1 \right) \geq n \frac{dR}{dn}.$$

Proposition 4 corresponds to Proposition 2 for Cournot-style markets for the case with linear demand. In part (a), the unifying condition is $\eta^S(\phi^S - 1) \geq (1 + L)/(\varepsilon^D - L)$ where $L = \theta^S$ under Cournot while $L = [1 - R]$ under Bertrand. The previous illustration of a Cournot-Nash quintopoly with $n = 5$ and $\varepsilon^D = 2$ (for which $L = \frac{1}{5}$) is replicated by setting the initial value of the substitution parameter $\gamma = 5$ so the aggregate diversion ratio is $R = .8$ and conversely, the firm-level price elasticity of demand $\varepsilon^d = 10$ (at symmetric equilibrium) leading to $\eta^S(\phi^S - 1) \geq \frac{2}{3}$. In part (b), the condition likewise corresponds directly to Proposition 2(b) with linear demand; it is again met where costs are convex $C'' > 0 \Leftrightarrow \eta^S > 0$ but the elasticity of the slope of marginal cost ϕ^S is sufficiently negative.

In general, going beyond this particular variant of a linear demand system, additional effects come into play also under price competition. Direct differentiation of the pass-through formula in Lemma 4 shows that:

$$\rho'(R) \leq 0 \Longleftrightarrow \left[\left(\eta^S + E^D - 1\right) + R \frac{\partial}{\partial R} \left(E^D + \eta^S\right) + \frac{\partial}{\partial R} \left(\eta^S(\varepsilon^D - 1)\right) \right] \geq 0.$$

Just like in quantity competition, Proposition 3's "between markets" condition is neither necessary nor sufficient for $\rho'(R) \leq 0$ to hold "within market". For example, if greater competition—as proxied by greater aggregate diversion R—amplifies demand convexity (higher E^D) and cost convexity (higher η^S) then the result may obtain even where $\eta^S < 1 - E^D$.

In sum, the main insights from the baseline model with homogeneous products extend to models of price competition with differentiated products.

7 Empirical implications

This section discusses the empirical implications and testability of the theory. An emerging literature at the intersection of industrial organization and public economics has begun to explore the empirical relationship between pass-through and market power (Miller, Osborne &

that $n\frac{dR}{dn} = \theta^S$. The changes in firm-level sales are also directly analogous, noting that $\frac{[2-R]}{n\frac{dR}{dn}} = \frac{(1+\theta^S)}{\theta^S}$.

Sheu 2017; Stolper 2018; Genakos & Pagliero 2019). These papers consider a single industry with multiple regional markets and—akin to Proposition 1 (Cournot) and Proposition 3 (Bertrand)—focus on cross-sectional differences in competition. However, while this literature also highlights the importance for pass-through of finer details on market conditions, it has so far engaged only little with the role of cost convexity and capacity constraints.

Genakos & Pagliero (2019) study the relationship between competition and pass-through using 2010 daily retail prices for gasoline in isolated markets on the Greek islands. They argue that the firm-level marginal cost of gasoline stations is approximately constant in their short-run setting, i.e., $\eta^S \approx 0$. In line with standard intuition, they find pass-through is just below .5 in monopoly markets and quickly rises towards 1 in markets with at least four firms. This is also remarkably consistent with a textbook Cournot model with linear demand and constant marginal cost, for which $\rho = 1/(1 + n^{-1})$ (Lemma 1 with $\theta = 1$, $\xi^D = 0$, $\eta^S = 0$). Put differently, taking together (i) the initial argument that costs satisfy $\eta^S \approx 0$, (ii) the cross-sectional estimates of cost pass-through, and (iii) a structural model of pass-through (that delivers Lemma 1), suggests that demand curves for gasoline on the Greek islands are approximately linear, $\xi^D \approx 0$.

Miller, Osborne & Sheu (2017) estimate pass-through rates around 1.3–1.8 using 30 years of annual data on the US Portland cement industry over the period 1980–2010. Their discussion of the institutional context also suggests that $\eta^S \approx 0$ is likely. By Lemma 1 (respectively, Lemma 4), pass-through above 1 means that demand must be log-convex with $\xi^D > 1$ (respectively, $E^D > 1$); by Proposition 1 (respectively, Proposition 3), cross-sectional pass-through is then unambiguously lower with greater competition. Using several measures of spatial rivalry, Miller et al. (2017) find evidence across different regional markets that is consistent with this theoretical prediction.[28] This is the reverse of the standard intuition—albeit driven by demand conditions rather than cost conditions.

Stolper (2018) estimates pass-through using 2007 daily firm- and market-level price data for 10,000 gasoline retail stations in Spain, with a primary interest in the distributional implications of fuel cost shocks. He finds an average cost pass-through rate of around .9, with the large majority of station-specific rates between .7–1.15. Moreover, greater market power—as proxied by a lower spatial density of competition and greater product branding—is strongly associated with *higher* pass-through. This finding appears to be potentially consistent with the condition of Proposition 1 (respectively, Proposition 3). However, as his analysis also assumes constant marginal costs, $\eta^S \approx 0$, the economic mechanism by which competition reduces pass-through may be more subtle. In principle, the theory with cost constraints can explain a "regime switch": if demand is log-convex, then changes in the value of η^S—across markets and/or over

[28] Ganapati, Shapiro & Walker (2020) estimate fuel cost pass-through in a panel of six homogenous-product US industries (boxes, bread, cement, concrete, gasoline, and plywood) and find large inter-industry heterogeneity. In their sample, cement is the most concentrated industry and has the highest pass-through (1.81) but they do not attempt like-for-like comparisons between industries so their results do not speak directly to Proposition 1.

time—can generate pass-through that lies above or below 1.[29]

Looking ahead, it would be valuable for future research to use longer periods of high-frequency data to study of the role of varying cost constraints—and test this paper's results. It seems clear that, in practice, many industries do at times experience "soft" capacity constraints and that industrial sectors can face "hard" constraints in the short-term. In terms of the "between markets" approach, as motivated by the Cobb-Douglas example discussed earlier, this suggests the capital-labour ratio as a proxy for soft capacity constraints. This could be used to control for cross-industry variation in η^S and thus help isolate the impact of market power on pass-through. In terms the "within market" approach, an empirical test could build on the work by Marion & Muehlegger (2011) who estimate pass-though in regional US gasoline markets and use metrics such as national refinery capacity utilization as proxies for supply-side constraints. In line with Lemma 1, they find that cost-pass-through is markedly lower during times when the industry is close to its (hard) capacity constraint—but do not test for the interaction with competition that underlies Proposition 2. A strong empirical research design could combine (i) exogenous variation that shifts market-wide marginal costs (leading to changes in τ) with (ii) shocks to operational industry capacity such as capacity shutdowns due to regulatory interventions or safety events (leading to changes in η^S).[30]

8 Conclusions and policy applications

Theoretical and empirical literature based on imperfect competition routinely assumes that firms have constant marginal costs. As a result, studies of pass-through and recent applications across fields including industrial organization, environmental economics and international trade, have focused on demand-side properties. More competition then raises pass-through as long as it lies below 1. The standard intuition thus suggests an appealing empirical test: any evidence of declining rates of cost pass-through would indeed be supportive of concerns about rising market power.

This paper has shown that this logic is perhaps surprisingly fragile. If firms have even modestly convex costs, then market power may increase pass-through. Much depends on higher-order properties of firms' demand curves and their cost functions as well as on the precise source

[29] An ideal empirical test would control for differences in both demand and cost conditions, such as $(\varepsilon^D, \xi^D, \eta^S)$ in Proposition 1. A typical empirical pass-through study includes demand controls that may plausibly account for variation in the demand elasticity ε^D. It is more challenging, however, to control for demand curvature ξ^D—which reflects the degree of heterogeneity in consumer valuations. This leads to possibility that empirical estimates could confound the impact of competition (differences in θ^S) on pass-through with those due to differences in higher-order demand conditions (differences in ξ^D).

[30] The events of the COVID-19 pandemic since early 2020 may also have led to periods of industrial competition characterized by cost shifts and capacity shocks that lend themselves to testing of pass-through theory in empirical work. Future research could also use the formulae in Lemma 1 for Cournot and Lemma 3 for Bertrand as estimating equations to quantify the contributions to pass-through, respectively, of the demand elasticity, demand curvature, cost curvature, and market power.

of greater market power—softer competitive conduct and/or higher market concentration. An immediate corollary is that the rate of pass-through of a shift in demand, that is, a uniform upward shift in consumers' willingness-to-pay, may—again perhaps counterintuitively—be less pronounced in a less competitive market.[31] A further implication is that "quantity pass-through" (Weyl & Fabinger 2013; Miklós-Thal & Shaffer 2021)—the rate of change in incumbents' *quantity* in response to a small amount of exogenous competitive entry—may also be higher with greater market power.[32]

The interplay between pass-through and market power plays an important role across several policy areas. The pass-through of fuel costs to retail electricity prices and gasoline prices regularly attracts the attention of competition policymakers (Federal Trade Commission 2011; Competition and Markets Authority 2015). A related antitrust issue is the "passing-on defense" by which the damages from an upstream cartel may be limited by downstream firms passing the overcharge onto their own customers (Verboven & Van Dijk 2009). The results in this paper suggest that the role of cost constraints may deserve more attention in economic analysis related to these policy areas. Under "tight" market conditions, when firms are subject to soft or hard capacity constraints, market power may be associated with higher—not lower—pass-through of a cost change.

Another application is the design of market-based regulation towards climate change for which the pass-through of a carbon price imposed on emissions-intensive industries (such as cement, electricity and steel) has central importance (Fabra & Reguant 2014; Miller, Osborne & Sheu 2017). The usual logic, going back to Buchanan (1969), is that the market-power distortion limits the extent of carbon cost pass-through—and therefore weakens the effectiveness of the carbon price (in the sense of the theory of the second-best). The results in this paper suggest that this is not necessarily the case, with potential implications for the extent to which different industrial sectors should be subject to carbon pricing.

In short, prices will be more reflective of marginal cost in a more competitive market but it does not follow that price changes will necessarily be more reflective of cost changes.

[31] This follows from the relationship: rate of cost pass-through + rate of demand pass-through = 1.

[32] For example, applying the results of Miklós-Thal & Shaffer (2021) to the situation depicted in Figure 1 (with linear demand) shows that quantity pass-through for a monopolist is .5 (and hence equal to its cost pass-through). By contrast, quantity pass-through is zero (and again equal to cost pass-through) under perfect competition as the incumbents still find it optimal to produce at capacity following a small amount of entry (i.e., market supply would rise to the now-expanded level of total capacity).

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Appendix

Proof of Lemma 1. The first-order condition, at symmetric equilibrium, of (2) can be written as:

$$0 = p(X) + \theta^S X p'(X) - \widehat{C}'(X/n) \equiv \Omega(X; \theta^S, n). \tag{5}$$

Differentiation gives:

$$\frac{\partial}{\partial \tau}\Omega(X; \theta^S, n) = -1, \tag{6}$$

using that costs satisfy $\widehat{C}'(x) = \tau + C'(x)$, as well as:

$$\begin{aligned} \frac{\partial}{\partial X}\Omega(X; \theta^S, n) &= p'(X) + \theta^S \left[p'(X) + Xp''(X)\right] - C''(X/n)\frac{1}{n} \\ &= p'(X)\left\{1 + \theta^S(1 - \xi^D) + \frac{1}{n}\frac{C''(x)}{-p'(X)}\right\} < 0, \end{aligned} \tag{7}$$

using the definition $\xi^D \equiv -Xp''(X)/p'(X)$. Hence the equilibrium rate of pass-through satisfies:

$$\rho \equiv \frac{\partial p}{\partial \tau} = p'(X)\frac{\partial X}{\partial \tau} = -p'(X)\frac{\frac{\partial}{\partial \tau}\Omega(X; \theta^S, n)}{\frac{\partial}{\partial X}\Omega(X; \theta^S, n)} = \frac{1}{\left[1 + \theta^S(1 - \xi^D) + \frac{1}{n}\frac{C''(x)}{-p'(X)}\right]}, \tag{8}$$

where

$$\frac{1}{n}\frac{C''(x)}{-p'(X)} = \frac{1}{n}\frac{xC''(x)}{\widehat{C}'(x)}\frac{\widehat{C}'(x)}{p}\frac{p}{-Xp'(X)}\frac{X}{x} = \eta^S\frac{(\varepsilon^D - \theta^S)}{\varepsilon^D}\varepsilon^D = \eta^S(\varepsilon^D - \theta^S), \tag{9}$$

using the definitions $\varepsilon^D = -p(X)/Xp'(X)$ and $\eta^S = \frac{x_i C''(x_i)}{\widehat{C}'(x_i)}$ (at symmetric equilibrium, $x_i = x$) and $L \equiv \varepsilon^D(p - \widehat{C}')/p = \theta^S$. So the expression for $\rho(\varepsilon^D, \xi^D, \eta^S, \theta^S)$ follows as claimed.

Proof of Proposition 1. Using the expression from Lemma 1, equilibrium cost pass-through in the two markets equals:

$$\rho(\theta_j^S) = \frac{1}{\left[1 + (\varepsilon^D - \theta_j^S)\eta^S + \theta_j^S(1 - \xi^D)\right]} \tag{10}$$

where θ_j^S is the competitive intensity in market $j = 1, 2$ and $(\varepsilon^D, \xi^D, \eta^S)$ are, by assumption, identical in both markets. Hence $\rho(\theta_1^S) \leq \rho(\theta_2^S)$ holds if and only if $(\theta_2^S - \theta_1^S)(\eta^S - 1 + \xi^D) \geq 0$ which boils down to $\eta^S + \xi^D \geq 1$, as claimed, since $\theta_2^S > \theta_1^S$ by assumption.

Proof of Lemma 2. Differentiating the expression for equilibrium cost pass-through from Lemma 1 gives:

$$\left.\frac{\partial \rho}{\partial \eta^S}\right|_{\varepsilon^D, \xi^D \text{ fixed}} = -\frac{(\varepsilon^D - \theta^S)}{[1 + \theta^S(1 - \xi^D) + \eta^S(\varepsilon^D - \theta^S)]^2} < 0 \tag{11}$$

and differentiating again for the cross-partial effect gives:

$$\frac{\partial}{\partial\theta^S}\left[\frac{\partial\rho}{\partial\eta^S}\right]_{\varepsilon^D,\xi^D \text{ fixed}} = \frac{\left[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)\right]+2(1-\xi^D-\eta^S)(\varepsilon^D-\theta^S)}{\left[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)\right]^3}. \tag{12}$$

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

Proof of Lemma 3. For part (a), on softer conduct, differentiating the symmetric first-order condition $\Omega(X;\theta^S,n)=0$ from (5) in the proof of Lemma 1 yields:

$$\frac{\partial}{\partial\theta}\Omega(X;\theta^S,n) = \frac{1}{n}Xp'(X) = xp'(X) < 0. \tag{13}$$

where also

$$\frac{\partial}{\partial X}\Omega(X;\theta^S,n) = p'(X)\left\{1+\theta^S(1-\xi^D)+\frac{1}{n}\frac{C''(x)}{-p'(X)}\right\} = \frac{1}{\rho}p'(X) < 0, \tag{14}$$

using the expression for ρ. So industry output and firm-level output respond according to:

$$\frac{dX}{d\theta} = -\frac{\frac{\partial}{\partial\theta}\Omega(X;\theta^S,n)}{\frac{\partial}{\partial X}\Omega(X;\theta^S,n)} - \rho x < 0 \Longrightarrow \frac{dx}{d\theta} = -\frac{1}{n}\rho x < 0 \tag{15}$$

and price according to:

$$\frac{dp}{d\theta} = p'(X)\frac{dX}{d\theta} = \left[-p'(X)X\right]\frac{1}{n}\rho > 0. \tag{16}$$

Hence firm-level output and price responses also satisfy:

$$\left.\frac{dx}{d\theta^S}\right|_{d\theta} = \frac{dx}{d\theta}\left[\frac{1}{d\theta^S/d\theta}\right] = -\frac{1}{n}\rho x n = -\rho x < 0 \tag{17}$$

and

$$\left.\frac{dp}{d\theta^S}\right|_{d\theta} = \frac{dp}{d\theta}\left[\frac{1}{d\theta^S/d\theta}\right] = \left[-p'(X)X\right]\frac{1}{n}\rho n = \left[-p'(X)X\right]\rho > 0. \tag{18}$$

For part (b), on fewer firms, rewrite the first-order condition at symmetric equilibrium from (5) as:

$$0 = p(xn) + \theta x p'(xn) - \widehat{C}'(x) \equiv \Gamma(x;\theta,n) \tag{19}$$

so that differentiation yields:

$$\begin{aligned}\frac{\partial}{\partial x}\Gamma(x;\theta,n) &= p'(xn)n + \theta\left[p'(xn)+xp''(xn)n\right] - C''(x)\\ &= p'(X)\left\{n+\theta(1-\xi^D)+\frac{C''(x)}{-p'(X)}\right\} = \frac{n}{\rho}p'(X) < 0,\end{aligned} \tag{20}$$

as well as:

$$\begin{aligned}\frac{\partial}{\partial n}\Gamma(x;\theta,n) &= p'(nx)x+\theta\left[xp''(nx)x\right] \\ &= x[p'(X)+(\theta/n)Xp''(X)] = p'(X)(1-\theta^S\xi^D)x<0. \end{aligned} \tag{21}$$

So firm-level output responds according to:

$$\frac{dx}{dn} = -\frac{\frac{\partial}{\partial n}\Gamma(x;\theta,n)}{\frac{\partial}{\partial x}\Gamma(x;\theta,n)} = -(1-\theta^S\xi^D)\frac{1}{n}\rho x<0. \tag{22}$$

As now $X(n)=nx(n)$, industry output satisfies:

$$\begin{aligned}\frac{dX(n)}{dn} &= x+n\frac{dx}{dn} = x\left[1-(1-\theta^S\xi^D)\rho\right] \\ &= x\left[1-\frac{(1-\theta^S\xi^D)}{[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)]}\right] \qquad (23) \\ &= x\left[\frac{\theta^S+\eta^S(\varepsilon^D-\theta^S)}{[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)]}\right] = \left[\theta^S+\eta^S(\varepsilon^D-\theta^S)\right]\rho x>0 \qquad (24)\end{aligned}$$

and price responds according to:

$$\begin{aligned}\frac{dp}{dn} &= p'(X)\frac{dX(n)}{dn} = p'(X)\left[\theta^S+\eta^S(\varepsilon^D-\theta^S)\right]\rho x \\ &= -\left[-p'(X)X\right]\frac{1}{n}\rho\left[\theta^S+\eta^S(\varepsilon^D-\theta^S)\right]<0. \end{aligned} \tag{25}$$

Hence output and price responses also satisfy:

$$\left.\frac{dx}{d\theta^s}\right|_{dn} = \frac{dx}{dn}\left[\frac{1}{d\theta^S/dn}\right] = -(1-\theta^S\xi^D)\frac{1}{n}\rho x\left[-\frac{n}{\theta^S}\right] = \frac{(1-\theta^S\xi^D)}{\theta^S}\rho x>0 \tag{26}$$

and

$$\begin{aligned}\left.\frac{dp}{d\theta^S}\right|_{dn} &= \frac{dp}{dn}\left[\frac{1}{d\theta^S/dn}\right] = \frac{n}{\theta^S}\left[-p'(X)X\right]\frac{1}{n}\rho\left[\theta^S+\eta^S(\varepsilon^D-\theta^S)\right] \\ &= \left[-p'(X)X\right]\rho\left[1+\eta^S\frac{(\varepsilon^D-\theta^S)}{\theta^S}\right]>0. \end{aligned} \tag{27}$$

thus completing the proof.

Proof of Proposition 2. From (3) in the main text, as implied by Lemma 1, $\frac{d\rho(\theta^S)}{d\theta^S}\geq 0$ if and only if:

$$\eta^S\left(1-\frac{d\varepsilon^D}{d\theta^S}\right)\geq(\varepsilon^D-\theta^S)\frac{d\eta^S}{d\theta^S}+\frac{d}{d\theta^S}\left[\theta^S(1-\xi^D)\right]. \tag{28}$$

For part (a), on softer conduct, using results for $\frac{dx}{d\theta^S}\Big|_{d\theta}$ and $\frac{dp}{d\theta^S}\Big|_{d\theta}$ from Lemma 3(a), it follows that the change in the price elasticity of demand ε^D satisfies:

$$
\begin{aligned}
\left.\frac{d\varepsilon^D}{d\theta^S}\right|_{d\theta} &= \left(\frac{d\varepsilon^D}{dp}\frac{p}{\varepsilon^D}\right)\frac{\varepsilon^D}{p}\left.\frac{dp}{d\theta^S}\right|_{d\theta} \\
&= \psi^D\frac{\varepsilon^D}{p}\left[-p'(X)X\right]\rho = \rho\psi^D = \rho\left[1+(1-\xi^D)\varepsilon^D\right], \qquad (29)
\end{aligned}
$$

where $\psi^D = \left[1+(1-\xi^D)\varepsilon^D\right]$ is the superelasticity of demand. Similarly, the change in the elasticity of marginal cost η^S satisfies:

$$
\begin{aligned}
\left.\frac{d\eta^S}{d\theta^S}\right|_{d\theta} &= \frac{d\eta^S}{dx}\left.\frac{dx}{d\theta^S}\right|_{d\theta} \\
&= -\frac{\eta^S}{x}\zeta^S\rho x = -\rho\eta^S\zeta^S = -\rho\eta^S(1+\phi^S-\eta^S), \qquad (30)
\end{aligned}
$$

where $\zeta^S = (1+\phi^S-\eta^S)$ is the superelasticity of marginal cost. Noting that it then also follows that:

$$
\begin{aligned}
\left(1-\left.\frac{d\varepsilon^D}{d\theta^S}\right|_{d\theta}\right) &= \frac{\left[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)\right]-\left[1+(1-\xi^D)\varepsilon^D\right]}{\left[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)\right]} \\
&= \rho\left[\eta^S-(1-\xi^D)\right](\varepsilon^D-\theta^S), \qquad (31)
\end{aligned}
$$

so that $\frac{d\varepsilon^D}{d\theta^S}\Big|_{d\theta} \leq 1$ if and only if $\eta^S \geq (1-\xi^D)$ (Proposition 1) and so the necessary and sufficient condition of (28) becomes:

$$
\rho\eta^S\left[\eta^S-(1-\xi^D)\right](\varepsilon^D-\theta^S) \geq -\rho\eta^S(1+\phi^S-\eta^S)(\varepsilon^D-\theta^S)+\frac{d}{d\theta^S}\left[\theta^S(1-\xi^D)\right] \qquad (32)
$$

or, rearranging:

$$
\rho\eta^S(\varepsilon^D-\theta^S)(\phi^S+\xi^D) \geq \frac{d}{d\theta^S}\left[\theta^S(1-\xi^D)\right], \qquad (33)
$$

from which the first claim follows immediately.

For the second claim—the sufficient condition—if demand is log-concave with $\xi^D \leq 1$, then cost pass-through $\rho \leq 1$ by Lemma 1. By assumption, demand curvature satisfies $\frac{d\xi^D}{dp} \geq 0$ so that $\frac{d}{d\theta^S}\left[\theta^S(1-\xi^D)\right] \leq (1-\xi^D)$, and so $\frac{d\rho(\theta^S)}{d\theta^S}\Big|_{d\theta} \geq 0$ is now implied by:

$$
\frac{(\varepsilon^D-\theta^S)}{\left[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)\right]}\eta^S(\phi^S+\xi^D) \geq (1-\xi^D), \qquad (34)
$$

using the expression for ρ from Lemma 1, which rearranges as:

$$
\eta^S\left(\phi^S-1+2\xi^D\right) \geq \frac{(1-\xi^D)\left[1+\theta^S(1-\xi^D)\right]}{(\varepsilon^D-\theta^S)}. \qquad (35)
$$

Supposing that the elasticity of the slope of marginal cost $\phi^S > 1 - 2\xi^D$ then this expression is easier to satisfy for higher values of η^S and so the assumption $\eta^S \geq (1 - \xi^D)$ implies that it is met whenever

$$\left(\phi^S - 1 + 2\xi^D\right) \geq \frac{\left[1 + \theta^S(1 - \xi^D)\right]}{(\varepsilon^D - \theta^S)} > 0, \tag{36}$$

which rearranges as

$$\phi^S + \xi^D \geq \frac{\left[1 + (1 - \xi^D)\varepsilon^D\right]}{(\varepsilon^D - \theta^S)} > 1 - \xi^D \geq 0 \tag{37}$$

where indeed $\phi^S > 1 - 2\xi^D$, so the second claim follows.

For part (b), on fewer firms, using results for $\frac{dx}{d\theta^S}\big|_{dn}$ and $\frac{dp}{d\theta^S}\big|_{dn}$ from Lemma 3(b), it follows that the change in the price elasticity of demand ε^D now satisfies:

$$\left.\frac{d\varepsilon^D}{d\theta^S}\right|_{dn} = \left(\frac{d\varepsilon^D}{dp}\frac{p}{\varepsilon^D}\right)\frac{\varepsilon^D}{p}\left.\frac{dp}{d\theta^S}\right|_{dn} = \rho\psi^D\left[1 + \eta^S\frac{(\varepsilon^D - \theta^S)}{\theta^S}\right], \tag{38}$$

while the change in the elasticity of marginal cost η^S satisfies:

$$\left.\frac{d\eta^S}{d\theta^S}\right|_{dn} = \frac{d\eta^S}{dx}\left.\frac{dx}{d\theta^S}\right|_{dn} = \frac{\eta^S}{x}\zeta^S\frac{(1 - \theta^S\xi^D)}{\theta^S}\rho x = \rho\eta^S\zeta^S\frac{(1 - \theta^S\xi^D)}{\theta^S}. \tag{39}$$

Again using Lemma 1 and $\psi^D = 1 + (1 - \xi^D)\varepsilon^D$, it then also follows that:

$$\begin{aligned}
\left(1 - \left.\frac{d\varepsilon^D}{d\theta^S}\right|_{dn}\right) &= \frac{\left[1 + \theta^S(1 - \xi^D) + \eta^S(\varepsilon^D - \theta^S)\right] - \left[1 + (1 - \xi^D)\varepsilon^D\right]\left[1 + \eta^S\frac{(\varepsilon^D - \theta^S)}{\theta^S}\right]}{\left[1 + \theta^S(1 - \xi^D) + \eta^S\left(\varepsilon^D - \theta^S\right)\right]} \\
&= \frac{\left[\eta^S - (1 - \xi^D)\right]\left(\varepsilon^D - \theta^S\right) - \left[1 + (1 - \xi^D)\varepsilon^D\right]\eta^S\frac{(\varepsilon^D - \theta^S)}{\theta^S}}{\left[1 + \theta^S(1 - \xi^D) + \eta^S\left(\varepsilon^D - \theta^S\right)\right]} \\
&= \rho\left[\left[\eta^S - (1 - \xi^D)\right] - \eta^S\frac{\left[1 + (1 - \xi^D)\varepsilon^D\right]}{\theta^S}\right](\varepsilon^D - \theta^S),
\end{aligned} \tag{40}$$

so that now $\frac{d\varepsilon^D}{d\theta^S}\Big|_{dn} \geq 1$ for any $\eta^S \geq 0$ if demand is log-concave $\xi^D \leq 1$ (as then $\left[1 + (1 - \xi^D)\varepsilon^D\right] \geq \theta^S$ always holds). Hence the necessary and sufficient condition of (28) becomes:

$$\begin{aligned}
&\rho\eta^S(\varepsilon^D - \theta^S)\left[\left[\eta^S - (1 - \xi^D)\right] - \eta^S\frac{\left[1 + (1 - \xi^D)\varepsilon^D\right]}{\theta^S}\right] \\
&\qquad \geq \rho\eta^S(\varepsilon^D - \theta^S)\zeta^S\frac{(1 - \theta^S\xi^D)}{\theta^S} + \frac{d}{d\theta^S}\left[\theta^S(1 - \xi^D)\right]
\end{aligned} \tag{41}$$

which rearranges as:

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

thus proving the first claim.

For the sufficient condition in the second claim, if demand is log-concave with $\xi^D\leq 1$, then cost pass-through $\rho\leq 1$ by Lemma 1, and $\frac{d}{d\theta^S}\left[\theta^S(1-\xi^D)\right]\leq(1-\xi^D)$ because $\frac{d\xi^D}{dp}\geq 0$, as in part (a). Hence $\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{dn}\geq 0$ is now implied by:

$$-\frac{\eta^S(\varepsilon^D-\theta^S)}{[1+\theta^S(1-\xi^D)+\eta^S(\varepsilon^D-\theta^S)]}\Bigg[\eta^S\left(\frac{(1-\theta^S)+(1-\xi^D)\varepsilon^D}{\theta^S}\right)$$
$$+(1-\xi^D)+\zeta^S\frac{(1-\theta^S\xi^D)}{\theta^S}\Bigg] \quad\geq\quad (1-\xi^D),$$

which rearranges as:

$$-\eta^S\zeta^S\frac{(1-\theta^S\xi^D)}{\theta^S} \quad\geq\quad (\eta^S)^2\left(\frac{(1-\theta^S)+(1-\xi^D)\varepsilon^D}{\theta^S}\right)+2(1-\xi^D)\eta^S$$
$$+\frac{(1-\xi^D)\left[1+\theta^S(1-\xi^D)\right]}{(\varepsilon^D-\theta^S)}\equiv G(\xi^D,\eta^S).$$

Noting that $G(\xi^D,\eta^S)>0$ it follows that the above condition can only be met if $\zeta^S<0$. Now using the assumptions that demand curvature satisfies $\xi^D\in[0,1]$ while cost curvature satisfies $\eta^S\in(0,1]$, so that also $0<(\eta^S)^2\leq\eta^S$, implies that $G(\xi^D,\eta^S)$ is bounded above according to:

$$G(\xi^D,\eta^S)\leq\eta^S\left(\frac{(1-\theta^S)+\varepsilon^D}{\theta^S}\right)+2\eta^S+\frac{(1+\theta^S)}{(\varepsilon^D-\theta^S)}=\eta^S\left(\frac{(1+\theta^S)+\varepsilon^D}{\theta^S}\right)+\frac{(1+\theta^S)}{(\varepsilon^D-\theta^S)} \quad (42)$$

so that a sufficient condition for $\left.\frac{d\rho(\theta^S)}{d\theta^S}\right|_{dn}\geq 0$ is:

$$-\frac{\eta^S}{\theta^S}\zeta^S\geq\eta^S\left(\frac{(1+\theta^S)+\varepsilon^D}{\theta^S}\right)+\frac{(1+\theta^S)}{(\varepsilon^D-\theta^S)} \quad (43)$$

which rearranges as:

$$-\zeta^S\geq\frac{\eta^S\left[(1+\theta^S)+\varepsilon^D\right]+\frac{\theta^S(1+\theta^S)}{(\varepsilon^D-\theta^S)}}{\eta^S}=\varepsilon^D+(1+\theta^S)\left[1+\frac{\theta^S}{\eta^S(\varepsilon^D-\theta^S)}\right], \quad (44)$$

thus completing the proof, also noting that this sufficient condition coincides with the previous necessary and sufficient condition where $\xi^D=0$ and $\eta^S=1$.

Proof of Lemma 4. At the symmetric equilibrium, the first-order condition writes as $(p - \widehat{C}') + \frac{D}{\frac{\partial D}{\partial p_i}} = 0$, where $D(p)$ is each firm's demand and $p(\tau)$ is the symmetric price in terms of the cost shifter. Differentiation shows that the rate of cost pass-through satisfies:

$$\frac{\partial p}{\partial \tau} = 1 + C'' \frac{\partial D}{\partial p} \frac{\partial p}{\partial \tau} - \frac{\partial}{\partial p} \left(\frac{D}{\frac{\partial D}{\partial p_i}} \right) \frac{\partial p}{\partial \tau} = 0 \Longrightarrow \rho \equiv \frac{\partial p}{\partial \tau} = \frac{1}{\left[1 + \frac{\partial}{\partial p} \left(\frac{D}{\frac{\partial D}{\partial p_i}} \right) - C'' \frac{\partial D}{\partial p} \right]} \tag{45}$$

recalling that $\widehat{C}'' = C''$. The two components can be re-expressed in terms of elasticities, firstly as:

$$\frac{\partial}{\partial p} \left(\frac{D}{\frac{\partial D}{\partial p_i}} \right) = \frac{\frac{\partial D}{\partial p} \frac{\partial D}{\partial p_i} - \frac{\partial}{\partial p} \left(\frac{\partial D}{\partial p_i} \right) D}{\frac{\partial D}{\partial p_i} \frac{\partial D}{\partial p_i}} = \frac{-\frac{\partial D}{\partial p} \frac{p}{D} + \frac{\frac{\partial}{\partial p} \left(\frac{\partial D}{\partial p_i} \right)}{\frac{\partial D}{\partial p_i}} p}{-\frac{\partial D}{\partial p_i} \frac{p}{D}} = \frac{\varepsilon^D - \varepsilon^m}{\varepsilon^d} \tag{46}$$

using the definitions of $(\varepsilon^d, \varepsilon^D, \varepsilon^m)$ as well as, secondly, as:

$$C''(D_i) \frac{\partial D}{\partial p} = \frac{D_i C''(D_i)}{\widehat{C}'(D_i)} \frac{\widehat{C}'}{p} \left(\frac{p}{D} \frac{\partial D}{\partial p} \right) = -\eta^S \left(\frac{\varepsilon^d - 1}{\varepsilon^d} \right) \varepsilon^D < 0. \tag{47}$$

and the expression for $\rho(\varepsilon^d, \varepsilon^D, \varepsilon^m, \eta^S)$ follows as claimed, where the stability condition $(\varepsilon^d + \varepsilon^D - \varepsilon^m) > 0$ implies that cost pass-through is always positive.

Proof of Proposition 3. Using the expression from Lemma 4 and the relationship $\varepsilon_j^d = \varepsilon^D / [1 - R_j]$, equilibrium cost pass-through in market $j = 1, 2$ equals

$$\rho(R_j) = \frac{1}{[1 + [1 - R_j](1 - E^D) + \eta^S (\varepsilon^D - [1 - R_j])]} > 0 \tag{48}$$

where $L_j = [1 - R_j]$ represents the competitive intensity in market $j = 1, 2$ and $(\varepsilon^D, E^D, \eta^S)$ are, by assumption, identical in both markets. Hence $\rho(R_1) \leq \rho(R_2)$ holds if and only if $(R_1 - R_2)(\eta^S - 1 + E^D) \geq 0$ which boils down to $\eta^S + E^D \geq 1$, as claimed, since $R_1 > R_2$ by assumption.

Proof of Lemma 5. The proof begins by deriving the equilibrium price and per-firm sales. With the linear structure of Shubik-Levitan demand,

$$\frac{\partial}{\partial p_i} D_i(\mathbf{p}) = -\frac{\beta}{n} \left(1 + \gamma(1 - \frac{1}{n}) \right) = -\frac{\beta}{n} \frac{1}{[1 - R]} \tag{49}$$

using $R = \gamma(n-1)/[n + \gamma(n-1)]$. Also, at symmetric equililibrium, $D_i = \frac{1}{n}(\alpha - \beta p) = D(p)$ so firm i's first-order condition becomes:

$$0 = (p - \widehat{C}')\frac{\partial D}{\partial p_i} + D = -\frac{\beta}{n}\frac{1}{[1-R]}(p - \widehat{C}') + \frac{1}{n}(\alpha - \beta p) \tag{50}$$

So the equilibrium price is:

$$p(\gamma, n) = \frac{[1-R](\alpha/\beta) + \widehat{C}'}{[2-R]} \tag{51}$$

and equilibrium per-firm sales are:

$$D_i(\gamma, n) = D(p(\gamma, n)) = \frac{1}{n}\left[\alpha - \beta p(\gamma, n)\right] = \frac{\beta}{n}\frac{1}{[2-R]}\left[(\alpha/\beta) - \widehat{C}'\right] > 0 \tag{52}$$

For part (a), on greater substitutability, the equilibrium price responds according to:

$$\begin{aligned}
\frac{dp}{d\gamma} &= \frac{\left\{-\frac{dR}{d\gamma}(\alpha/\beta) + C''\frac{\partial D_i}{\partial p}\frac{dp}{d\gamma}\right\}[2-R] + \frac{dR}{d\gamma}\left\{[1-R](\alpha/\beta) + \widehat{C}'\right\}}{[2-R]^2} \\
&= \frac{-\frac{dR}{d\gamma}\left\{(\alpha/\beta) - \widehat{C}'\right\} + C''\frac{\partial D_i}{\partial p}\frac{dp}{d\gamma}[2-R]}{[2-R]^2} \\
&= -\frac{dR}{d\gamma}\frac{\frac{n}{\beta}D_i}{[2-R]} - \frac{\frac{\beta}{n}C''}{[2-R]}\frac{dp}{d\gamma},
\end{aligned} \tag{53}$$

where the last line uses the previous expression for D_i as well as $\frac{\partial D_i}{\partial p} = -\frac{\beta}{n} < 0$. Solving for $\frac{dp}{d\gamma}$ now gives:

$$\frac{dp}{d\gamma} = -\frac{dR}{d\gamma}\frac{1}{\left[[2-R] + \frac{\beta}{n}C''\right]}\frac{n}{\beta}D_i = -\frac{dR}{d\gamma}\rho\frac{n}{\beta}D_i < 0 \tag{54}$$

which uses that cost pass-through $\rho = \frac{1}{\left[[2-R]+\frac{\beta}{n}C''\right]} > 0$ by Lemma 4, and is negative because the diversion ratio satisfies

$$\frac{dR}{d\gamma} = \frac{(1-\frac{1}{n})}{\left(1+\gamma(1-\frac{1}{n})\right)^2} > 0. \tag{55}$$

Firm-level sales respond according to:

$$\frac{d}{d\gamma}\left[D_i(p(\gamma, n), n)\right] = \frac{d}{d\gamma}\left[\frac{1}{n}(\alpha - \beta p)\right] = -\frac{\beta}{n}\frac{dp}{d\gamma} = \frac{dR}{d\gamma}\rho D_i > 0. \tag{56}$$

Hence price and output responses also satisfy:

$$\left.\frac{dp}{dR}\right|_{d\gamma} = \left[\frac{1}{\frac{dR}{d\gamma}}\right]\frac{dp}{d\gamma} = -\frac{n}{\beta}\rho D_i < 0 \tag{57}$$

and

$$\left.\frac{dD_i}{dR}\right|_{d\gamma} = \left[\frac{1}{\frac{dR}{d\gamma}}\right]\frac{dD_i}{d\gamma} = \rho D_i > 0, \tag{58}$$

as claimed.

For part (b), on more firms, noting that firm i's equilibrium demand $D_i(p(\gamma,n),n) = \frac{1}{n}(\alpha - \beta p(\gamma,n))$ depends both directly and indirectly on the number of firms n, the equilibrium price

$$p(\gamma,n) = \frac{[1-R](\alpha/\beta) + \widehat{C}'}{[2-R]} \tag{59}$$

responds according to:

$$\frac{d}{dn}\widehat{C}'(D_i(p(\gamma,n),n)) = C''(D_i)\left(\frac{\partial D_i}{\partial n} + \frac{\partial D_i}{\partial p}\frac{dp}{dn}\right) \tag{60}$$

and so:

$$\begin{aligned}
\frac{dp}{dn} &= \frac{\left\{-\frac{dR}{dn}(\alpha/\beta) + C''\left(\frac{\partial D_i}{\partial n} + \frac{\partial D_i}{\partial p}\frac{dp}{dn}\right)\right\}[2-R] + \frac{dR}{dn}\left[[1-R](\alpha/\beta) + \widehat{C}'\right]}{[2-R]^2} \\
&= \frac{-\frac{dR}{dn}\left[(\alpha/\beta) - \widehat{C}'\right] + [2-R]C''\left(\frac{\partial D_i}{\partial n} + \frac{\partial D_i}{\partial p}\frac{dp}{dn}\right)}{[2-R]^2} \\
&= -\frac{n}{\beta}\frac{D_i\frac{dR}{dn}}{[2-R]} + \frac{C''\left(\frac{\partial D_i}{\partial n} - \frac{\beta}{n}\frac{dp}{dn}\right)}{[2-R]},
\end{aligned} \tag{61}$$

where the last line uses the previous expression for D_i as well as $\frac{\partial D_i}{\partial p} = -\frac{\beta}{n} < 0$. Solving for $\frac{dp}{dn}$ now gives:

$$\frac{dp}{dn} = \frac{-\frac{n}{\beta}D_i\frac{dR}{dn} + C''\frac{\partial D_i}{\partial n}}{\left[[2-R] + \frac{\beta}{n}C''\right]} = -\left[\frac{n}{\beta}\frac{dR}{dn} + \frac{1}{n}C''\right]\rho D_i < 0 \tag{62}$$

which uses that cost pass-through $\rho = \frac{1}{\left[[2-R]+\frac{\beta}{n}C''\right]} > 0$ and $\frac{\partial D_i}{\partial n} = -\frac{1}{n^2}(\alpha - \beta p) = -\frac{1}{n}D_i < 0$ and is negative because the diversion ratio satisfies:

$$\frac{dR}{dn} = \frac{\gamma\frac{1}{n^2}}{\left(1+\gamma(1-\frac{1}{n})\right)^2} > 0. \tag{63}$$

Thus firm-level sales respond according to:

$$\begin{aligned}
\frac{d}{dn}\left[D_i(p(\gamma,n),n)\right] &= \frac{\partial D_i}{\partial n} + \frac{\partial D_i}{\partial p}\frac{dp}{dn} = -\frac{1}{n}D_i - \frac{\beta}{n}\frac{dp}{dn} \\
&= -\left(\frac{1}{n} - \frac{\left[\frac{\partial R}{\partial n} + \frac{1}{n}\frac{\beta}{n}C''\right]}{\left[[2-R] + \frac{\beta}{n}C''\right]}\right)D_i \\
&= -\left(\frac{1}{n}[2-R] - \frac{\partial R}{\partial n}\right)\rho D_i < 0
\end{aligned} \tag{64}$$

which is negative because:

$$\frac{1}{n}[2-R] > \frac{\partial R}{\partial n} \Longleftrightarrow \frac{1}{n}\frac{\left(2+\gamma(1-\frac{1}{n})\right)}{\left(1+\gamma(1-\frac{1}{n})\right)} > \frac{\gamma\frac{1}{n^2}}{\left(1+\gamma(1-\frac{1}{n})\right)^2} \Longleftrightarrow \left(2+\gamma(1-\frac{1}{n})\right) > \frac{\gamma\frac{1}{n}}{\left(1+\gamma(1-\frac{1}{n})\right)} \tag{65}$$

which is always satisfied for all values of γ, n.

Hence price and output responses also satisfy:

$$\left.\frac{dp}{dR}\right|_{dn} = \left[\frac{1}{\frac{dR}{dn}}\right]\frac{dp}{dn} = -\left[\frac{\frac{n}{\beta}\frac{dR}{dn}+\frac{1}{n}C''}{\frac{dR}{dn}}\right]\rho D_i = -\left[1+\frac{\frac{\beta}{n}\frac{1}{n}C''}{\frac{dR}{dn}}\right]\frac{n}{\beta}\rho D_i < 0 \tag{66}$$

and

$$\left.\frac{dD_i}{dR}\right|_{dn} = \left[\frac{1}{\frac{dR}{dn}}\right]\frac{dD_i}{dn} = -\left[\frac{\frac{1}{n}[2-R]-\frac{\partial R}{\partial n}}{\frac{\partial R}{\partial n}}\right]\rho D_i = -\left[\frac{\frac{1}{n}[2-R]}{\frac{\partial R}{\partial n}}-1\right]\rho D_i < 0, \tag{67}$$

as claimed.

Proof of Proposition 4. For part (a), recalling that the rate of cost pass-through is

$$\rho = \frac{1}{\left[[2-R]+\frac{\beta}{n}C''(D_i)\right]} \tag{68}$$

greater substitutability reduces pass-through if and only if:

$$\frac{d\rho}{d\gamma} \leq 0 \Longleftrightarrow \frac{\beta}{n}C'''(D_i)\frac{dD_i}{d\gamma} \geq \frac{dR}{d\gamma}. \tag{69}$$

From (56) in the proof of Lemma 5(a):

$$\frac{dD_i}{d\gamma} = \frac{dR}{d\gamma}\rho D_i > 0 \tag{70}$$

so that the required condition on pass-through is equivalent to:

$$\frac{\beta}{n}C'''(D_i)\frac{dR}{d\gamma}D_i \geq \frac{dR}{d\gamma}\left[[2-R]+\frac{\beta}{n}C''(D_i)\right] \tag{71}$$

whih rearranges as:

$$\frac{\beta}{n}\left(C'''D_i - C''\right) = \frac{\beta}{n}C''(\phi^S - 1) \geq [2-R] \tag{72}$$

using the definition of the elasticity of the slope of marginal cost, $\phi^S \equiv \frac{D_i C'''(D_i)}{C''(D_i)}$.

For part (b), as firm i's demand $D_i(p(\gamma,n),n) = \frac{1}{n}(\alpha - \beta p(\gamma,n))$ depends both directly and indirectly on the number of firms n, write the rate of cost pass-through is

$$\rho = \frac{1}{\left[[2-R]+\frac{\beta}{n}C''(D_i(p(\gamma,n),n))\right]} \tag{73}$$

so that a larger number of firms reduces pass-through if and only if:

$$\frac{d\rho}{dn} \leq 0 \Longleftrightarrow \frac{d}{dn}\left[\frac{\beta}{n}C''(D_i(p(\gamma,n),n))\right] \geq \frac{dR}{dn} \tag{74}$$

which rearranges as:

$$\begin{aligned}\frac{dR}{dn} &\leq -\frac{\beta}{n^2}C''(D_i(p(\gamma,n),n)) + \frac{\beta}{n}\left[C'''\frac{d}{dn}\left[D_i(p(\gamma,n),n)\right]\right] \\ &= \frac{\beta}{n}\left[C'''\frac{d}{dn}\left[D_i(p(\gamma,n),n)\right] - \frac{1}{n}C''\right]. \\ &= \frac{\beta}{n}C''\left[\frac{C'''}{C''}\frac{d}{dn}\left[D_i(p(\gamma,n),n)\right] - \frac{1}{n}\right] \end{aligned} \tag{75}$$

From (64) in the proof of Lemma 5(b):

$$\frac{d}{dn}\left[D_i(p(\gamma,n),n)\right] = -\left(\frac{1}{n}[2-R] - \frac{dR}{dn}\right)\rho D_i < 0 \tag{76}$$

so that the required condition on pass-through is equivalent to:

$$\begin{aligned}\frac{dR}{dn} &\leq \frac{\beta}{n}C''\left[-\frac{C'''}{C''}\left(\frac{1}{n}[2-R] - \frac{dR}{dn}\right)\rho D_i - \frac{1}{n}\right] \\ &= \frac{\beta}{n}C''\left[-\frac{1}{n}\phi^S\frac{\left[[2-R] - n\frac{dR}{dn}\right]}{\left[[2-R] + \frac{\beta}{n}C''\right]} - \frac{1}{n}\right]\end{aligned} \tag{77}$$

using $\phi^S \equiv \frac{D_i C'''(D_i)}{C''(D_i)}$ and $\rho = \frac{1}{\left[[2-R]+\frac{\beta}{n}C''(D_i)\right]}$, and thus immediately yielding the result as claimed.