

Strategically delayed price adjustment in oligopoly and aggregated price dynamics

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Abstract

It is shown that staggered and sticky price adjustment is possible without *ad hoc* frictions, and without suspending full price flexibility. I consider an oligopoly with n price-setting firms which can strategically choose the timing of price decisions and thus the stage in a n -stage Stackelberg oligopoly game. After a shock, firms can credibly signal to delay their price adjustment for some time to (re-)establish a leader-follower structure. From the calculus behind this decision, it is derived which firm will adjust at which time and therefore stage of the game. The delays are in general asymmetric with respect to direction and size of the shock, and they depend on market power, making the model consistent with a large variety of empirical stylized facts. Strategically delayed adjustment of firm prices implies also inertia in aggregated price level adjustment which plays a key role in macroeconomics.

Keywords: oligopoly, leader-follower structures, price dispersion, delayed price adjustment, cost shock, aggregated price dynamics

JEL Classification: D21, D43, L11, L16, E31

1 Introduction

Price rigidities are at the heart of New Keynesian Macroeconomics. Established explanations of such rigidities typically rely on some sort of frictions such like cost of price changes (à la Rotemberg (1982), Golosov and Lucas (2007), Alvarez et al. (2022)) or temporary inability to change a price (à la Calvo (1983)), or informational frictions (e.g. Sims (2003), Reis (2006), Mankiw and Reis (2002), Woodford (2009), tracing back to Lucas (1972) signal extraction problem). A recent comprehensive overview over price setting models with frictions can be found in Costain and Nakov (2025). While these mechanisms provide microeconomic rigor once their foundational assumptions are accepted, many economists – as noted by Blanchard (2025) – remain uneasy about their *ad hoc* nature. By grounding inertia in frictions, the literature implicitly suggests that rational behavior under full flexibility would necessarily avoid efficiency losses from price stickiness.

This paper demonstrates that such *ad hoc* frictions are unnecessary to explain price stickiness. The central contribution is a model where price sluggishness emerges as a *strategic choice* in a frictionless environment, without suspending the assumption of full price flexibility. With “frictionless” I mean that there are no external constraints for smooth adaption of the choice which does not rule out that firms could credibly commit not to adjust by intention. By shifting the focus to the “generic market form” of a heterogeneous oligopoly – of which perfect and monopolistic competition are merely edge cases – I show that firms strategically utilize their flexibility to decide not only how to change prices, but also *when*. The core mechanism, related to the war of attrition literature, facilitates the endogenous establishment of leader-follower structures. In a symmetric oligopoly, firms benefit from sequential play compared to a simultaneous Bertrand-Nash outcome. Under certain conditions, the follower’s benefit exceeds the leader’s, creating a strategic incentive to adjust prices later than rivals (Gal-Or (1985)). In this framework, the absence of frictions does not lead to Walrasian efficiency but instead enables more sophisticated consumer rent extraction through enhanced markups. This approach provides a promising explanation for various empirical stylized facts, including asymmetric responses to shock direction and size. In particular, it explains the asymmetry between large and small shocks (Cav-allo et al. (2024)), and between positive and negative cost shocks (Peltzman (2000)). Furthermore, by considering a dispersion of shocks, the model derives aggregate price dynamics that is similar to the Poisson arrival rates of Calvo models, but with a firm strategic foundation.

The existing literature on price setting based on frictions is extensive (see e.g. Costain and Nakov (2025)). This paper bridges the gap between macroeconomic

models of rigidity and industrial organization (IO) timing games.

Macroeconomic Foundations and Rigidities

Current macroeconomic models often integrate strategic interactions but remain anchored in exogenous frictions. [Wang and Werning \(2022\)](#) explore how market concentration affects inertia, yet their framework relies on Calvo-type Poisson arrival rates. Similarly, [Gasteiger and Grimaud \(2023\)](#) endogenize price-setting frequencies to derive a non-linear Phillips Curve, but maintain the basic Calvo structure. Models by [Alvarez et al. \(2011\)](#) and [Devereux and Siu \(2007\)](#) combine time- and state-dependent rules – highlighting asymmetric responses to shocks – but ultimately ground these dynamics in ad hoc “timing costs”. Also [Ascari and Rossi \(2012\)](#) point out that state-dependent and time-dependent models have very different implications regarding output and inflation as a response to large shocks and trend inflation. In contrast, for small shocks, state- and time-dependent models show the same (first-order) results, as [Auclert et al. \(2024\)](#) show. The model presented in this paper departs from these by showing that strategic interaction alone generates inertia, thereby having time- *and* state-dependent characteristics, including asymmetric responses to small and large shocks. A frictionless approach of modeling staggered price setting is provided by [Bhaskar \(2002\)](#) which requires strategic interaction not only between firms of the same market but across different industries, and a bit artificial assumption of price setting in even and odd periods.

Endogenous Timing and War of Attrition

In IO literature, the incentive for sequential play is well-established. [Hamilton and Slutsky \(1990\)](#) and [Robson \(1990\)](#) prove that in markets with strategic complements, a sequential Stackelberg structure is the unique subgame perfect outcome when firms choose their decision timing. However, these foundations often lack a physical time dimension or rely on artificial “timing costs” ([Robson \(1990\)](#); [Zhu et al. \(2014\)](#)). While [Pastine and Pastine \(2004\)](#) and [Kim et al. \(2021\)](#) utilize “delay costs” and consumer loyalty to explain why leadership positions change, they do not derive absolute delay times applicable to macroeconomic dynamics. Similarly, [van Damme and Hurkens \(2004\)](#) emphasize that cost heterogeneity determines leadership incentives, but do not address transition dynamics. [Amir and Stepanova \(2006\)](#) also address cost heterogeneity and suggest risk dominance as a selection device for the endogenous choice of the leader-follower structure. For strategic substitutes with quantity competition, [Anderson and Engers \(1994\)](#) endogenize the timing of market entry by strategic investment decisions. But there, all firms prefer the leader position. Competing for the favourable follower position by delaying price adjustment is closely related to the war of attrition in continuous time where both player have asymmetric cost of waiting ([Hendricks et al. \(1988\)](#)).

Information Asymmetry and Signaling

Strategic delay is frequently associated with information asymmetry in bargaining (Admati and Perry (1987)), global games (Larson (2016)), market entry (Gunay (2008)), or uninformed consumers (L’Huillier and Zame (2022)). In these contexts, delay serves to coordinate beliefs or facilitate learning. While I acknowledge that idiosyncratic shocks create uncertainty, I emphasize that the strategic incentive for delay exists even under complete information. Furthermore, unlike models where leadership is coordinated through potentially collusive price announcements (Harrington and Ye (2019); Harrington (2022); Janssen and Karamychev (2025)), I argue that timing signals alone can facilitate leader-follower structures. Empirical studies of the US automotive sector (Roy et al. (1994)) and evidence of tacit collusion in transparent markets (Kauffman and Wood (2007)) support the real-world relevance of these strategic timing decisions.

This paper contributes by deriving absolute delay times directly from the net present value of profit flows in case of a credible commitment to delay adjustment. It demonstrates that price stickiness is an equilibrium phenomenon of market power that persists under full flexibility. The remainder of the paper is structured as follows: chapter 2 develops the core strategic calculus, chapter 3 maps these theoretical insights into aggregate price dynamics via a Gamma distribution. Chapter 4 concludes.

2 Strategic delay of price adjustment

2.1 Equilibrium leader-follower structures

First, we need to show that firms have a genuine interest in price setting in a sequential leader-follower structure. We can use well established results for the duopoly case (i.e. Hamilton and Slutsky (1990)), and extend it to n firms. Consider an industry with n symmetric firms with constant marginal costs c , supplying a heterogeneous good, and using the price as the strategic variable. Throughout the paper we consider pure strategies only. We do not consider capacity constraints or other additional strategic variables – except for the *timing* of the price decision. Hence, we have a n -firm oligopoly with strategic complementarity in prices. We assume downwards sloped demand curves and thus concavity of the profit function in order to guarantee the existence of an economically meaningful Bertrand-Nash equilibrium. In such an equilibrium we have $p_i = BR(\mathbf{p}_{-i}) \forall i = 1, \dots, n$ with $\mathbf{p}_{-i}$ as the price vector of all firms except for i , and BR as the best response function.

It is well known for Bertrand duopolies that sequential price setting in a leader-follower structure is beneficial for both, where the follower is relatively even better off

than the leader in case of symmetric firms (Gal-Or (1985)). The leader i maximizes $\max_{p_i} \pi_i(p_i, p_j = BR(p_i))$ with the solution p^L . The follower then sets $p^F = BR(p^L)$. These leader-follower structures (or Stackelberg games) require a *logical* sequence of decision making, called *stages*. The term *follower* doesn't necessarily imply the she makes the decision "later" in physical time. If firms could decide about the stage (as a part of their strategy), both will clearly prefer to make decisions on different rather than on the same stage. This is a well established result by Hamilton and Slutsky (1990) (Theorem IV, Theorem VI) and Robson (1990), see also Deneckere and Kovenock (1992). Hamilton and Slutsky (1990) investigate various cases of downwards and upwards sloped best response functions. For the case of strategic complementary, they prove that a sequential play is the unique subgame perfect outcome when players can decide about the stages. The graphical illustration of the proof is straightforward (see figure 1). In the Bertrand-Nash solution both iso-profit curves form a lens (price combinations which lead to a Pareto improvement), and both best response functions are within this lens, so any of both Bertrand-Stackelberg solutions must be in this area, and are thus superior. As we consider symmetric firms, also the prices in the Bertrand-Nash solution, p^N , are identical. Given the slopes of the best response functions, we then obtain $p^L > p^F > p^N$ as the firms are symmetric. This translates into lower market shares and profits for the leader as compared to the follower (Gal-Or (1985)). Hence, it is then more attractive to achieve the follower position.

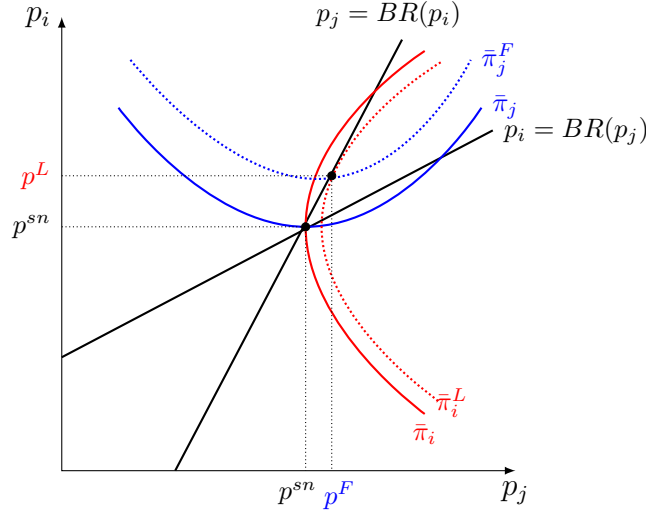


Figure 1: Incentive for endogenous leader-follower structure

Hamilton and Slutsky (1990) refer to their result as *endogenous timing*. Although stages are just a logical sequence, they argue that practically firms *react* to *observed* actions of their rivals. Hence, they interpret the endogenous formation of a sequence

as an outcome of (a kind of) conjectural variation. However, in their paper they do not explicitly model what happens “in between” two price decisions. If we would start from $t = 0$ where the market comes into existence, is there market exchange *before* the follower has set his price? And how long does it take before setting (or adjusting) a price? Does this have an impact on the timing decision? This is the focus of the present paper as we are interested in *measurable* delay times.

The first step is to generalize the [Hamilton and Slutsky \(1990\)](#) result to the case of n firms. In general, these firms can engage in a m -stage Stackelberg game with $m \in \{1, 2, \dots, n\}$ which means that they can set all prices simultaneously ($m = 1$), or each firm sets the price on an own stage ($m = n$), or any combination of sequential price decision of some firms, and simultaneous pricing of others ($1 < m < n$). In the following, we assume continuous time which means that by choosing a certain point in time, firms thereby choose the stage within a leader-follower structure. Once when two firms decide on the same stage s , it is then possible that one of them deviates to $s - 1$ or $s + 1$ without changing the sequence of the other players. We need to consider a solution where $k \leq n$ firms decide simultaneously on the same stage, and thus playing mutually best response against each other. We say that these firms form a “block” B within the set of all firms. Due to symmetry, all prices of these k firms will be identical. On this stage we can present the k firms as a game between one firm i and $k - 1$ remaining firms. This refers to so-called *full aggregative games* (see [Cornes and Hartley \(2012\)](#), [Acemoglu and Jensen \(2013\)](#)) which allows us to write $u_i(p_i, \mathbf{p}_{-i}, \cdot) = v_i(p_i, g(\mathbf{p}), \cdot)$ where $g : \mathbb{R}^k \rightarrow \mathbb{R}$ as a price aggregator which is a continuously differentiable. The dot indicates that the payoff function is also determined by prices of potential leaders and followers of this block B , to be discussed later on. Using v_i , we represent the behavior of the block B as a 2-player interaction of player i and $B \setminus \{i\}$. Firm i ’s best response can then be expressed as best response *against the price aggregate* of the other players. As we have symmetric firms, we can treat p_{-i} as a singleton, so that for simplicity we write $p_i^* = BR_i(p_{-i})$. The uniform behavior of the remaining block members, including their simultaneous mutual best response, is denoted by $p_{-i}^* = BR_{-i}(p_i)$.

Assumptions (A.1): In the following, we consider a n -player oligopoly game with the following properties: (a) all firms are symmetric with respect to their (initial) cost and the demand function which is twice differentiable, (b) goods are heterogeneous and substitutes, (c) we have strategic complementarity in prices, (d) profit functions are quasi-concave, (e) firm i ’s strategy consists of a price p_i and the timing $t \in [0, \infty)$ of the price decision in continuous time, so that the firm also decides about the stage s_i within a leader-follower structure, (f) prices and timing decisions are observable.

Lemma 1: Given an oligopoly game with assumptions (A.1). Let $G^{(k)}$ denote a game structure where the firms decide in a sequence with $k \leq n$ stages, implying that there is at least one block B of simultaneously deciding firms if $k < n$. Hence, $G^{(1)}$ represents the full simultaneous game with the Bertrand-Nash solution and the corresponding profit vector $\pi^{(1)}$, while $G^{(n)}$ represents the full n -stage Stackelberg game with corresponding profit vector $\pi^{(n)}$. Then we have a Pareto ranking $\pi^{(1)} \leq \pi^{(2)} \leq \dots \leq \pi^{(n)}$.

Proof: Consider a given $G^{(k)}$ with $k < n$. The step from k to $k+1$ implies that one member i of any block B on certain stage s decides to deviate to $s-1$ or $s+1$, thereby creating an additional leader-follower relationship between i and the remaining block members in a resulting game $G^{(k+1)}$. Due to strategic complementarity this implies higher prices and profits of i and the remaining block members, but also higher prices and profits of all leaders and followers of the (former) block B as we have $\partial \pi_i / \partial p_j > 0$ according to (A.1). Hence $\pi^{(k)} \leq \pi^{(k+1)}$ element-wise for any k . The price-ranking is a special application of the [Milgrom and Roberts \(1990\)](#) result on supermodular games, the profit-ranking results from strategic complementarity. $\square$

This Pareto rank characterization does not yet say anything about strategic behavior of the firms within these structures, on SPNE paths and off-path, and their incentive to deviate. The next step is to show that only a full n -stage leader-follower structure can be SPNE.

Lemma 2: Given an oligopoly game with assumptions (A.1). Then no m -stage Stackelberg solution with $m < n$ can be SPNE. Only a n -stage Stackelberg solution can be a SPNE.

Proof: Consider a game $G^{(m)}$ with $m < n$ which implies that a number k of firms decide on stage s *simultaneously* (block B), while $k_L \geq 0$ players set prices prior to s , and $k_F \geq 0$ players are followers (hence $k_L + k + k_F = n$). Let i be a member of block B which maximizes own profit function on the same stage as the $k-1$ rivals from the same block. More precisely, $p_i^* = \arg \max_{p_i} \pi_i(p_i, \mathbf{p}_{-i}, \cdot)$ with $\mathbf{p}_{-i}$ as the $k-1$ vector of rival prices. The dot in the profit function indicates, that profits are also determined by the pre-committed leader prices p_L and the anticipated follower prices p_F . It is not important whether the k_L and the k_F firms also play simultaneously or in a staggered manner. The leader prices are pre-committed and hence appear as a parameter in the payoff function. The follower prices are anticipated best responses to all previously set prices so that we can treat p_F as an aggregate which endogenously depends on pre-committed leader prices as well as on p_i and $\mathbf{p}_{-i}$. Hence, i 's payoff function depends on $p_i, \mathbf{p}_{-i}$ only. The behavior of the block B members can be represented as an aggregative game where $p_j = p \forall j \in B$ is the symmetric Nash solution, and $p_i = BR_i(p_{-i})$ is the best response of i , and $p_{-i} = BR_{-i}(p_i)$ is an aggregated best response of all other

players against p_i but mutually best response to each other of the $k - 1$ firms, thereby setting a uniform price, so that we can interpret p_{-i} as a singleton in this context. Observe that the best response functions, starting from the Nash solution p , lie in the Pareto superior set. Hence, firm i has an incentive to commit to play at stage $s - 1$ or stage $s + 1$, that means: to deviate from the decision to choose stage s . Firm i will benefit from deviation irrespective of whether the remaining block $B \setminus \{i\}$ remains to stay a block or to dissolve in further small blocks, or to dissolve completely. As a consequence of lemma 1, any further erosion of the remaining block creates more leader-follower relationships, thereby increasing prices and profits so that also firm i will benefit. In other words, for any SPNE price paths after firm i 's decision, i has an incentive to deviate from stage s . But this recursively applies to the remaining block $B \setminus \{i\}$ and any block we might have in game $G^{(m)}$. It follows, that for any firm it cannot be part of a subgame perfect strategy to remain within a block. Hence, no game structure $G^{(m)}$ with $m < n$ can be a SPNE. A situation where there is no incentive to deviate from chosen stage is then a full hierarchy solution for $G^{(n)}$. $\square$

Lemma 2 does not yet establish existence of an SPNE. With costless timing, any first mover could move behind the last mover. Section 2.2 shows that the cost of waiting with a stale price, based on commitment, leads to a determinate sequence in the full hierarchy game.

From a macroeconomic perspective, the leader-follower structure is already an interesting result: price (and thus markup) *dispersion* though having symmetric firms is not due to frictions but an outcome of market power. Price dispersion is not transitory but can be seen as an equilibrium phenomenon which also fits to empirical observations (De Loecker et al. (2020), Peters (2020), Kaplan and Menzio (2015), Sheremirov (2020)). It is a leverage of markups compared to the Bertrand-Nash solution and hence an additional source of consumer welfare loss. As higher market power comes with higher markups, leader-follower structures could increase markup dispersion and amplify average markups which could have macroeconomic consequences such like decline of the labor share (De Loecker et al. (2020), Autor et al. (2020)), resource misallocation (Peters (2020)), and higher price stickiness (Wang and Werning (2022)).

A key idea is that we do not consider a fictitious situation where “a market comes into existence”. Instead, we start already with a market in a Stackelberg equilibrium and analyse how prices adjust to a (cost) shock. In particular, we are interested how firms are able to re-establish a leader-follower structure with reset prices though having limited knowledge about the rival's shocks. It turns out that the ability to delay adjustment provides a mechanism not only to signal the idiosyncratic shock, but in particular to establish a leader-follower structure. Hence, the suppliers have a mutual interest to establish such a mechanism as a coordination device. Firms have to consider

several effects: how strong does the shock hit the firm (positively or negatively), how large are the benefits from being in a late (follower) stage of the game relative to the leader position, how large are the losses when being attacked by rival's best response while keeping the old price? From that we will derive the maximum delay time, beyond which the benefit from delaying price adjustment turns negative. This leads to a sequence of delay times and thus enables a new leader-follower structure. Given that after a shock the costs might substantially differ, it is also no longer guaranteed that the follower position is preferable. There might be cases where there is no rivalry for the follower position or rivalry for the leader position. In these cases, the proposed mechanism does not necessarily imply price stickiness.

In a later section where the influence of the number of firms on expected delay of adjustment is investigated, it is pointed out that with increasing n , all Stackelberg profits shrink and converge to the Bertrand-Nash profits. This happens quite quickly even for not very large n . A simple and empirically relevant alternative market structure, proposed in the literature, is that there are many firms, but only few firms dominate the market by having a huge market share, while the majority of firms are very small. Evidence for such structures can be found in [De Loecker et al. \(2020\)](#), [Autor et al. \(2020\)](#), and [Chen et al. \(2006\)](#). The small firms have negligible influence on the market outcome and thus behave like under monopolistic competition. They can be modeled as a “fringe” firm while the few dominating firms are engaged in a Stackelberg game, taking the given behavior of the fringe into account (see [Cherry \(2000\)](#), [Tasnádi \(2000\)](#), [Tasnádi \(2004\)](#) for oligopoly analysis with a fringe). As we do not have any frictions, the fringe firms would immediately respond to the shock, while the few dominant firms delay their response strategically. I pick up this idea in the last section of this chapter.

2.2 The incentive to delay adjustment

How could firms arrange a leader-follower structure? A mechanism is proposed where firms can produce credible signals to delay price adjustment after a shock, depending on how much worth it is to get into a late stage of the Stackelberg game. I start with a variant without signalling, and argue why this works only for $n = 2$. The mechanism is related to the war of attrition literature ([Fudenberg and Tirole \(1986\)](#), [Hendricks et al. \(1988\)](#)) for the continuous time case, but we will not obtain the instant-exit equilibrium which determines a sequence but not creating a physical delay. Again, consider an oligopoly with n symmetric firms $i = 1, \dots, n$, and assumptions (A1) hold true. Given Lemma 2, we initially start in a n -stage Stackelberg equilibrium. Now consider a cost shock $\bar{dc} + dc_i$ where $dc_i \sim \mathcal{N}(0, \sigma^2)$ and $Cov[dc_i, dc_j] = 0$ for any $i \neq j$. This means that every firm is exposed to a shock which has a common component $\bar{dc}$

and an idiosyncratic component dc_i which is private knowledge. We ask how firms could re-arrange a leader-follower structure after the shock, and this mechanism is based on strategic delay.

Two major issues arise from this shock structure: first, as the idiosyncratic shock component is private knowledge, firms cannot perfectly know the best response function of their rival – and thus also not calculate exact profits for the leader and follower position. Strategic delay decisions thus have to be made with *expected* behavior of their rivals. Once when a firm optimally adjusts its price, the underlying idiosyncratic shock is revealed. Second, idiosyncratic cost shocks make the firms asymmetric. For the case of asymmetry is no longer guaranteed that the follower position is preferred to the leader position. In case of significant cost differences we may have $\pi_i^L > \pi_i^F$ for at least one firm i . Then there is no case for a strategic delay of this firm. Hence, delayed price adjustment, also in aggregate, requires that at least some firms have “sufficiently similar” costs after the shock so that they are in rivalry for a late follower position. The following approach of strategic delay addresses these two problems.

To illustrate the general setup with low notation effort, consider the case of a duopoly. As we start with symmetric firms, and as the common shock component $\bar{dc}$ doesn’t affect symmetry, we define $\mathcal{F}$ as the set of all (dc_1, dc_2) -combinations such that for both firms it is $E\pi_i^F > E\pi_i^L, i = 1, 2$ which implies rivalry for the attractive follower position. As it is known that rival’s idiosyncratic shock has zero mean and a given variance, the expected profits in each position can be approximated by a second-order Taylor approximation around the mean:

$$E\pi_i \approx \pi_i(E dc_j = 0) + \frac{1}{2} \frac{\partial^2 \pi_i}{\partial dc_j^2} \sigma_j^2 \quad (1)$$

The shocks hit different firms differently, not only because of their different idiosyncratic shock size and direction but mainly because firms have been in a different Stackelberg position prior to the shock. Hence, their position after a shock is genuinely asymmetric. The idea is that the firm which benefits from the follower position relatively more (compared to the situation with stale prices) will be more “patient” and thus able to delay price adjustment longer than the rival. This is the classical *war of attrition* game. Note that the exact benefits from achieving the follower position are private knowledge because of the idiosyncratic shock, but also the profits in the waiting position when a firm keeps the old stale price unchanged is also private knowledge because of the same reason.

Duopoly case without signalling

Assume that duopoly firms have no opportunity to signal how long they are willing to delay adjustment. The maximum delay time t_i^* , a firm i is willing to keep the old

price before benefits from follower position are gone, is given by t_i^* which solves

$$\int_0^{t_i^*} \beta^t E\pi_i^W dt + \int_{t_i^*}^{\infty} \beta^t E\pi_i^F dt = \int_0^{\infty} \beta^t E\pi_i^L dt \quad (2)$$

$$\Rightarrow t_i^* = \max \left\{ 0, \frac{\log \left(\frac{E\pi_i^W - E\pi_i^L}{E\pi_i^W - E\pi_i^F} \right)}{\log(\beta)} \right\} \quad (3)$$

with $E\pi^L, E\pi^F$ as the expected leader and follower profits, and $E\pi^W(p_i = p_i(0), p_j = p_j(0))$ as the “waiting profits” where both firms keep their stale prices prior to the shock. The l.h.s. of (2) is the net present value of profits when firm i keeps its old price unchanged until t_i^* and then switching to the follower position (winning the war of attrition), while the r.h.s. is the net present value of profit if firm i adopts the leader position immediately (the exit option in the war of attrition). Thus, $t_i^*(\bar{dc}, dc_i)$ is a concession function which determines the maximum acceptable delay before the benefits from the follower position are gone, compared to immediate concession to adopt the leader position. Hence, $t^{**} = \min\{t_1^*, t_2^*\}$ will be the maximum delay when the “weaker” firm concedes by playing the leader price, while the other firm will respond with the follower price immediately. As communication is not possible and maximum concession times are private knowledge, it will be unclear who will win the war of attrition until the first firm exits. As firms might form expectations about rival’s cost shock and get more pessimistic, the longer they are waiting, the concession time of the first mover will be *lower* than the maximum t^{**} (Fudenberg and Tirole (1986)).

The war of attrition story suggests that $E\pi^W$ is quite low as both firms stick at sub-optimal prices. This is obviously true in case of a cost increase. In case of cost decline $\bar{dc} < 0$, however, best response functions shift, and the old price vector is within a “collusion zone”. It may happen that $E\pi^L < E\pi^W < E\pi^F$ so that waiting is no longer a threat compared to the leader position. Calculus (3) has no longer a real solution, and we cannot derive an economically meaningful concession time. For strong cost reduction shocks, the waiting position could be even very comfortable with $E\pi^L < E\pi^F < E\pi^W$. In this case, concession times would turn negative. Hence, (3) makes a zero cut. In these cases waiting is not painful *as long as the rival is waiting, too*. But permanent collusive behavior cannot be subgame-perfect. If a firm could credibly commit to wait, the rival is invited to deviate and to play best response, making waiting much less attractive. There is no inherent mechanism how both firms could re-establish a leader-follower structure by strategic delay in case of strong cost declines.

Further, this approach has the disadvantage that we can not easily scale it up to

$n > 2$ firms. Although we can compute concession times for each stage k , where the exit option is not becoming the very first leader but the stage- k player, we have the difficulty that all firms on previous stages $k - 1$ need to re-arrange their prices such that p_k is the best response to it. This would require that the $k - 1$ rivals could anticipate the concession times in advance. If they can't do that, they will *optimally respond* to a new concession price p_k . But then stage- k player is de facto the first mover. It would not have paid off to postpone the price decision.

Another obstacle of this approach is the case of absence of idiosyncratic shocks (or when $\sigma \rightarrow 0$). Then the concession times t_1^*, t_2^* can be mutually anticipated. As the loser of the war of attrition is common knowledge, one could immediately arrange the Stackelberg solution in $t = 0$. However, this is not necessarily subgame perfect. As the stronger firm, say i , is able to postpone adjustment until t^{**} , firm j might have an incentive to start playing best response against i 's stale price in $t = 0$ once when the profits of this best response play exceed the leader profits. As this is a credible threat, i will respond by keeping the old price until t^{**} and then play best response to p_i which will thus adjust to p_i^L in t^{**} . As we will see below, we obtain the same scenario also with idiosyncratic shocks plus signalling.

Because of the vital interest of all $n > 2$ firms to establish a Stackelberg sequence, this mechanism of strategic delay without signalling will not work in case of idiosyncratic shocks. But this can be achieved once when credible signalling is possible.

Duopoly case with signalling

There is an incentive to signal delay times t_i^*, t_j^* according to an individual concession function. Note, that the idiosyncratic value of the follower position $E\pi_i^F$ is known ex ante. Hence, a firm does not have an incentive to overbid and run into a winner's curse. Thus, exaggerated large signals which should intimidate the rival's are non-credible. Once when the signals reveal $t_j^* < t_i^*$, firm j has lost the war of attrition and will adjust the price immediately. In case of $E\pi_j^{BR}(p_i = p_i(0), p_j = BR(p_i(0))) > E\pi_j^L$, it is a credible threat that firm j will play best response against the stale price of the rival until the rival's concession time $t^{**} = \min\{t_i^*, t_j^*\}$ instead of moving into the leader position immediately. Obviously this is a credible threat, making the waiting position of the rival more costly. Hence, the calculation of the concession times in eq. (3) needs to take the best response play into consideration, leading to a *re-definition of the waiting profits*: $E\pi_i^W(p_i = p_i(0), p_j = BR(p_i(0)))$, which implies a certain shift of the concession time scale. A subgame perfect strategy rules out that the winner i waits longer than necessary because the earlier he achieves the follower position, the higher the expected payoff. But it also rules out to make any premature adjustment prior to $t^{**} = \min\{t_i^*, t_j^*\}$ and thus to surprise the rival. In such a case, the rival will answer by playing best response, and thus the leader-follower sequence flips: the

winner is no longer the winner. Hence, the commitment to delay to t^{**} is *credible*. So any off-path behavior will be credibly punished by rival's best response play, implying loss of the follower position. In the other case $p_j^{BR} \leq p_j^L$, firm j plays p_j^L in $t = 0$, and the winner responds with p_i^F immediately. Thus, we have no delay (instant exit solution). Analogously to the set $\mathcal{F}$, we need to check whether the idiosyncratic shock of the loser j is within the set $\mathcal{G}_j$ of shocks dc_j such that $p_j^{BR} > p_j^L$. Only then we will obtain a strategic delay of price adjustment.

There is a subtle problem to be addressed: as j 's idiosyncratic shock is not known by i , how could i know whether the price p_j set in $t = 0$ is p_j^L or p_j^{BR} ? Here, i can exploit j 's concession function: with the known time $t_j^* = t_j^*(\bar{dc}, dc_j)$ there will be not many idiosyncratic shocks dc_j consistent with t_j^* (in case of linear demand function, for example, we have only two solutions). Hence, only one solution will be consistent with the observed price p_j so that the shock is revealed, and i knows whether p_j is best response play or a leader's price. The results so far can be summarized:

Proposition 1: Given a duopoly, and assumptions (A.1) hold true. The initial situation is a 2-stage Stackelberg equilibrium. Consider a shock $\bar{dc} + dc_i$ ($i = 1, 2$) with $dc_i \sim \mathcal{N}(0, \sigma^2)$ and zero covariance, and $(dc_1, dc_2) \in \mathcal{F}$. The idiosyncratic component is private knowledge while $\bar{dc}$ is public knowledge. Both firms calculate and signal t_i^* according to eq. (3) (with π^W as the waiting profits while rival plays best response) to determine the maximum delay for postponing reset prices in order to get the follower position. Assume without loss of generality $t_j^* < t_i^*$. Firms decide about price paths $p_i(t), i = 1, 2$. There exists a strategic delay t^{**} such that

$$p_i(t) = \begin{cases} p_i(0) & \text{for } t < t^{**} \\ BR_i(p_j(t)) & \text{else} \end{cases} \quad \text{and} \quad p_j(t) = \begin{cases} BR_j(p_i(t)) & \text{for } t < t^{**} \\ p_j^L & \text{else} \end{cases}$$

is a SPNE with $t^{**} = t_j^*$ if $dc_j \in \mathcal{G}_j$ and $t^{**} = 0$ else.

Proof: Firms have an incentive to report the signals t_i^*, t_j^* according to eq. (3) as they know the value of the follower position and want to avoid winner's curse. Signals below these concession times would diminish the likelihood of winning the war of attrition. Let $t^{**} = \min\{t_i^*, t_j^*\} = t_j^*$ the delay commitment of i , and $dc_j \in \mathcal{G}_j$. This commitment is credible as there is no incentive to wait longer than necessary in order to achieve the favorable follower position. Any delay $t > t^{**}$ reduces the payoff. The same holds true for any premature deviation at $t < t^{**}$ as this would induce a new best response of rival j and thus i will lose the follower position. Further, there is no incentive to commit right away to a time prior to t^{**} as this incentivizes j to wait an increment longer and thus winning the war of attrition. Consider the case $dc_j \in \mathcal{G}_j$ so that $\pi_j^{BR} \geq \pi_i^L$. Firm j has no incentive to deviate from the strategy for any $t < t^{**}$ as

it credibly plays best response. As it is anticipated that i will switch to best response play from $t \geq t^{**}$, the optimal behavior of j is to play p_j^L in t^{**} . Any deviation from that is inferior. Best response of i is thus $p_i(t) = p_i^F$ for $t \geq t^{**}$. So any off-path play of a firm is credibly punished by the best response play of the rival who will thus get into the favorable follower position. In case of $dc_j \notin \mathcal{G}_j$, firm j , knowing that i is in the waiting position, has an incentive to play p_j^L immediately and thus force i to deviate from any delay announcement and adopting the follower position immediately. In this case it is $t^{**} = 0$ as an edge case. $\square$

The advantage of the signalling version is that for $n > 2$ firms, the signals $\{t_1^*, t_2^*, \dots, t_n^*\}$ are common knowledge. It is not so important how exactly they are computed, as long as they facilitate a subgame perfect time path to one of the $n!$ full-hierarchy Stackelberg solutions. The waiting position of i then could be defined as a scenario where all $n - 1$ rivals constitute a $(n - 1)$ -stage Stackelberg as a best response to i 's stale price. After the first firm adopts immediately and thereby revealing the idiosyncratic shock, one might allow for updating the signals $t_i^{*,k}$, given this new information. At any stage k where firms $i = 1, 2, \dots, n - k$ are still in the waiting position, the concession time at stage k , $t_k^{**} = \min\{t_1^{*,k}, t_2^{*,k}, \dots, t_{n-k}^{*,k}\}$. As we are not much interested in the (slight) quantitative changes of delay times due to updating, but in the general effect of n on expected delay times, we will not compute such updates in the later section.

2.3 Linear demand scheme

We apply the model of delay signals to the case of an oligopoly market with a linear demand scheme. Linear demand functions are quite unusual in macroeconomics as it is inconsistent with CRRA household utility functions which are typically used in the literature (for a microeconomic foundation of linear demand schemes see [Amir et al. \(2017\)](#), and recently [Pellegrino \(2025\)](#) for the case of product differentiation). But as it is possible to analytically derive best response functions and also the delay times t_i^*, t_i^{**} , we use the linear case to demonstrate how this approach works, and how the resulting delay times depend on size and direction of the shock but also on the discount factor β and the substitution elasticity. The more common case of an iso-elastic demand function will be discussed in the subsequent section. It will turn out that the qualitative results are nearly the same.

Consider a demand function $q_i = \frac{y}{n} - b(p_i - \bar{p})$ with $\bar{p} = \frac{1}{n} \sum_i p_i$ as the average price (the price index in the linear case). It is Y a shifter, reflecting the market size, and parameter $b > 0$ determines the elasticity of substitution, i.e. how sensitive demand responds to differences between the price and the average price. In this section we consider $n = 2$. The profit functions are $\pi_i = (p_i - c_i)q_i$ where $c_i = c$

before the shock, and $c_i = c + \bar{dc} + dc_i$ after the shock as explained above. The best response functions and profits $\pi_i^F, \pi_i^L, \pi_i^W$ are easy to calculate and omitted here. After the shock, the cost are no longer identical, and we have to compute the set $\mathcal{F}$ of (dc_i, dc_j) -combinations where $E\pi_i^F \geq E\pi_i^L$ and $E\pi_j^F \geq E\pi_j^L$ which means that there is rivalry for the follower position. Recall, that the common shock $\bar{dc}$ has no effect on symmetry. In case of a linear demand function this is a convex set which can be easily determined by equalizing $E\pi_i^F = E\pi_i^L$ and solving for dc_i , which gives $dc_i \in (m - \sqrt{8m^2 - \sigma^2}, m + \sqrt{8m^2 - \sigma^2})$ for $i = 1, 2$, with $m = y/b$, and $\mathcal{F}$ is the product of the two intervals.

Given the observed own idiosyncratic shock as well as the commonly known shock $\bar{dc}$, and given the initial position of firm i in the Stackelberg equilibrium, we can compute $E\pi_i^F, E\pi_i^L$ and $E\pi_i^W$, and hence we obtain t_i^* from equation (3). Doing the same for j , and selecting the lower value $t^{**} = \min\{t_i^*, t_j^*\}$, we obtain delay times t^{**} on the (dc_i, dc_j) plane as depicted in figure 2 for various values of common shocks $\bar{dc}$, and a given sample parameterization¹. As $t_i^*(\bar{dc}, dc_i)$ with given $E_i[dc_j] = 0$ and therefore independent from the realized dc_j , and vice versa for the other firm, the contour lines for $t^{**} = \min(t_1^*, t_2^*)$ are “pyramid-shaped” (left panel, figure 2, where x-axis is dc_1 and y-axis is dc_2). The light yellow color indicates the highest delay, the more the color turns to dark blue, the lower is the delay. Observe that the maximum delay is *not* centered at the origin where we have the highest probability mass of the joint distribution of idiosyncratic shocks. The black areas in the graphic denote the case where the shock of the conceding firm i lies outside its set $\mathcal{G}_i$. All depicted shock combinations are within $\mathcal{F}$. For the linear case, the set $\mathcal{G}_i$ can be easily obtained by computing the roots of $f(dc_i) = E\pi_i^{BR}(dc_i) - E\pi_i^L(dc_i)$. The function has a unique minimum for a $dc_i > 0$ with $f(dc_i) < 0$ in case of $\bar{dc} = 0$. The larger $\bar{dc}$, the more the area with negative values $f(dc_i) < 0$ shifts to the left so that more probability mass is on $dc_i \notin \mathcal{G}_i$. Hence, one should expect that for positive common shocks it is more likely to arrive at a situation where both firms have an interest in a very quick re-arrangement into a Stackelberg solution ($t^{**} = 0$). Negative shocks with temporarily higher markups, instead, will imply longer delays.

Using the joint probability function $p(dc_1, dc_2)$, we can compute the probability density for each t^{**} (numerical PDF). On the right panel of figure 2 depicts the numerically derived CDFs (black curve). It turns out that the distribution of positive delays can be approximated quite well by a Γ distribution. The entire distribution (red curves) is a weighted mix of a Dirac mass for the case $t^{**} = 0$ and a Gamma function for all $t^{**} > 0$ where the weights are determined by $\pi_0 = \text{prob}(t^{**} = 0)$: $F(t) = \pi_0 \mathbf{1}(t \geq 0) + (1 - \pi_0)\Gamma(t > 0)$. It allows to compute the expected delay time

¹The baseline parameterization for the graphic is $y = 100, b = 20, c = 20, \beta = 0.95, \sigma = 2$.

for each common shock. Throughout chapter 2, t is an unspecified “model time”. In chapter 3, I will discuss how model time can be related to physical calendar time.

The cost shocks hit the former leader and the former follower differently. We investigate how likely it is that the previous leader-follower position maintains or reverts. For the given parameterization and the given shocks from figure 2 we determine the combinations of idiosyncratic shocks where the announced delays are $t_1^* = t_2^*$. These are depicted in figure 3. In the area between the blue curves which represent all combinations with $t_1^* = t_2^*$, we have a switch of the positions, while in the areas above/below the upper/lower blue curve the previous Stackelberg position prevail. The green and purple dashed lines enclose all combinations where $dc_1 \notin \mathcal{G}_1$ and $dc_2 \notin \mathcal{G}_2$. Given the parameterization, all points are within $\mathcal{F}$. The intercepts with the blue lines thus determines the area where $t^{**} > 0$, and the corresponding lines then turn yellow to depict the area of positive delays. This explains the nonlinear shapes of the black areas in fig. 2. The area inside the circle represents 99% of the probability mass as we have assumed a standard deviation $\sigma = 2$ of the idiosyncratic shocks.

We now explore the determinants of expected delay times $E[t^{**}]$ after common shocks more systematically. In figure 4 we see the expected delay times as a function of the common shock $\bar{dc}$. Given the numerical parameterization, the displayed shocks are up to $\pm 40\%$ of the cost (x -axis). We obtain the following results which are robust against variations of the parameter set. The expected delay times for each common shock stem from an integration of the delay times from idiosyncratic shock combinations. Therefore, we also have an expected delay for $\bar{dc} = 0$ which is hard to interpret as there is no change of the Stackelberg prices. However, idiosyncratic shocks might lead to a switch of leader-follower positions after some delay.

(a) There is an asymmetry regarding the shock size: small shocks lead to longer expected delays than large shocks. This is a quite intuitive result as large shocks makes it more painful to stay with a sub-optimal old price while being aggressively attacked by the rival’s best-response play, thus implying lower delays. In the appendix it is shown that the functions $t_i^*(\bar{dc})$ are single-peaked, and the peak of $\min\{t_1^*, t_2^*\}$ is negative but close to zero. The result is in line with state-dependent inflation models which have a lot of empirical support (Luo and Villar (2025), Dedola et al. (2025), Ascari and Haber (2022)). As Cavallo et al. (2024) formulate: “*Large shocks travel fast*”. While in case of small shocks, the differences between Calvo-type (time-dependent) and Rotemberg-type (state-dependent) friction-based models are small (Midrigan (2011)), this seems not to be the case for large shocks which lead to less inertia and thus being consistent with state-dependent models (Karadi and Reiff (2019)). The model result also fits to the empirical approach of estimated hazard functions: the higher the misalignment of the price after a shock, the higher is the probability of a price change (see Luo and

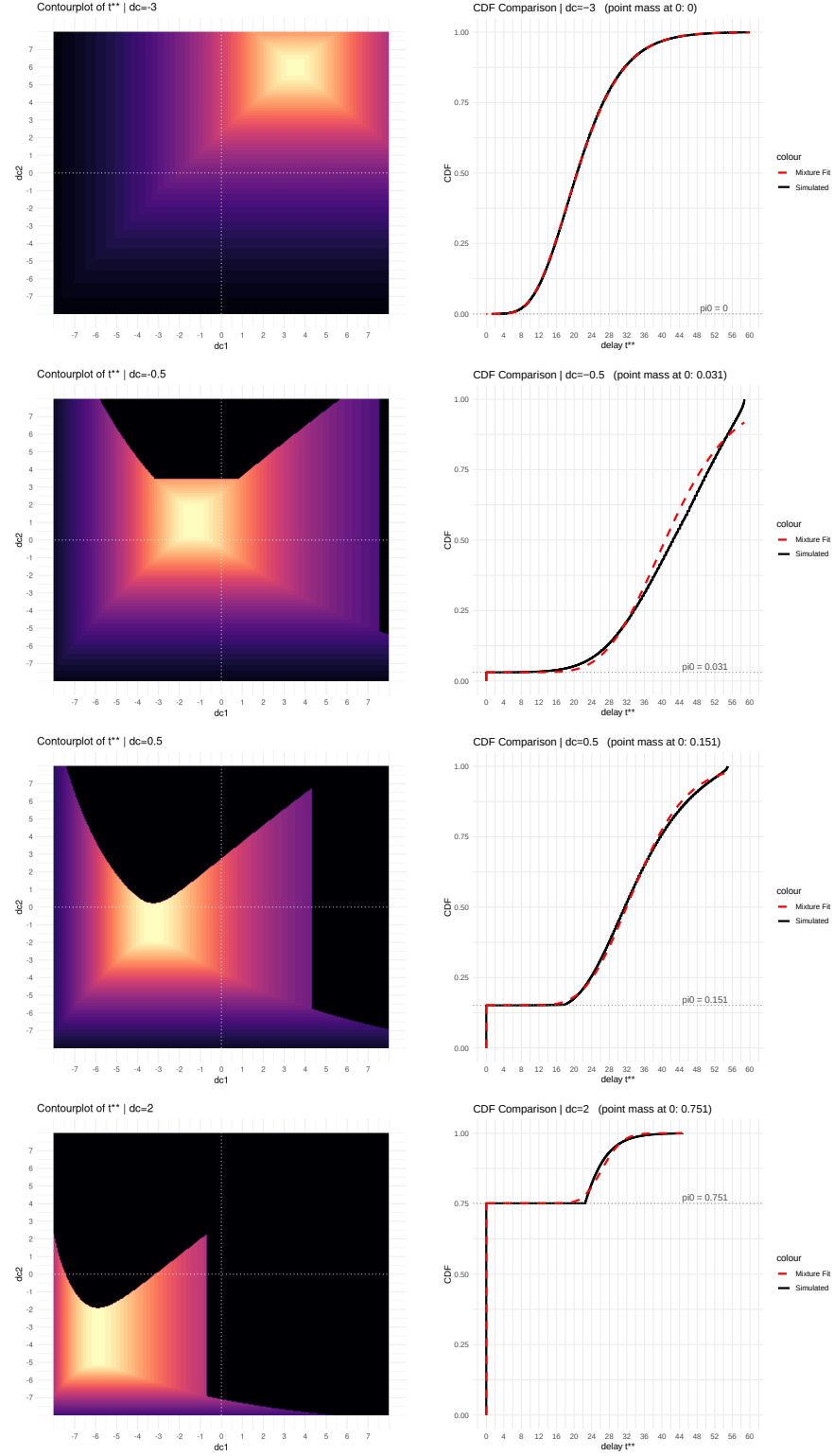


Figure 2: Delay times, depending on idiosyncratic shocks; common shocks $\bar{dc} = \{-15\%, -2.5\%, +2.5\%, +10\%\}$ (from top to bottom)

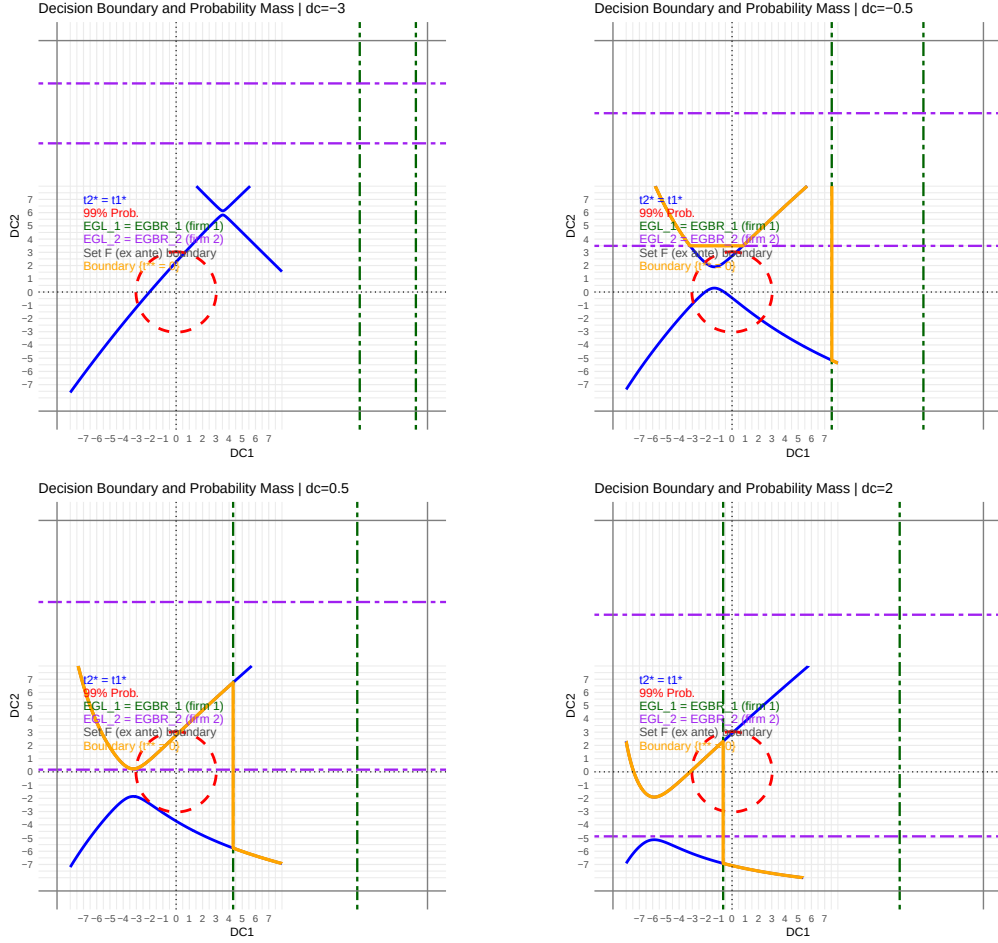


Figure 3: Preserving or reverting the leader-follower position due to a shock; common shocks $\bar{dc} = \{-15\%, -2.5\%, +2.5\%, +10\%\}$ (from left to right, from top to bottom)

Villar (2025)).

(b) There is an asymmetry regarding positive and negative shocks: for negative shocks (sudden decline of cost) the expected delays are larger than for cost increases of same size. The main reason is that cost decline shocks imply that stale prices are within a collusion zone so that the waiting position is more comfortable compared to a corresponding positive cost shock of the same size. The opportunity cost of patiently waiting in the war of attrition are lower for negative cost shocks. Further, for medium and large positive shocks, delay times approach zero. This results from the fact that for positive shocks it is more likely that $dc_i \notin \mathcal{G}_i$ as explained above, so that both firms have an interest in a quick arrangement of a Stackelberg solution. The probability of such an event, depending on $\bar{dc}$, is depicted in figure 5. Also this confirms economic intuition and empirical observations (Peltzman (2000), Dias et al. (2015), Gwin (2009), Gagliardone et al. (2025)), in particular in gasoline markets (Borenstein et al. (1997)) which inspired the “*rockets and feather*” metaphor. It is also in line with

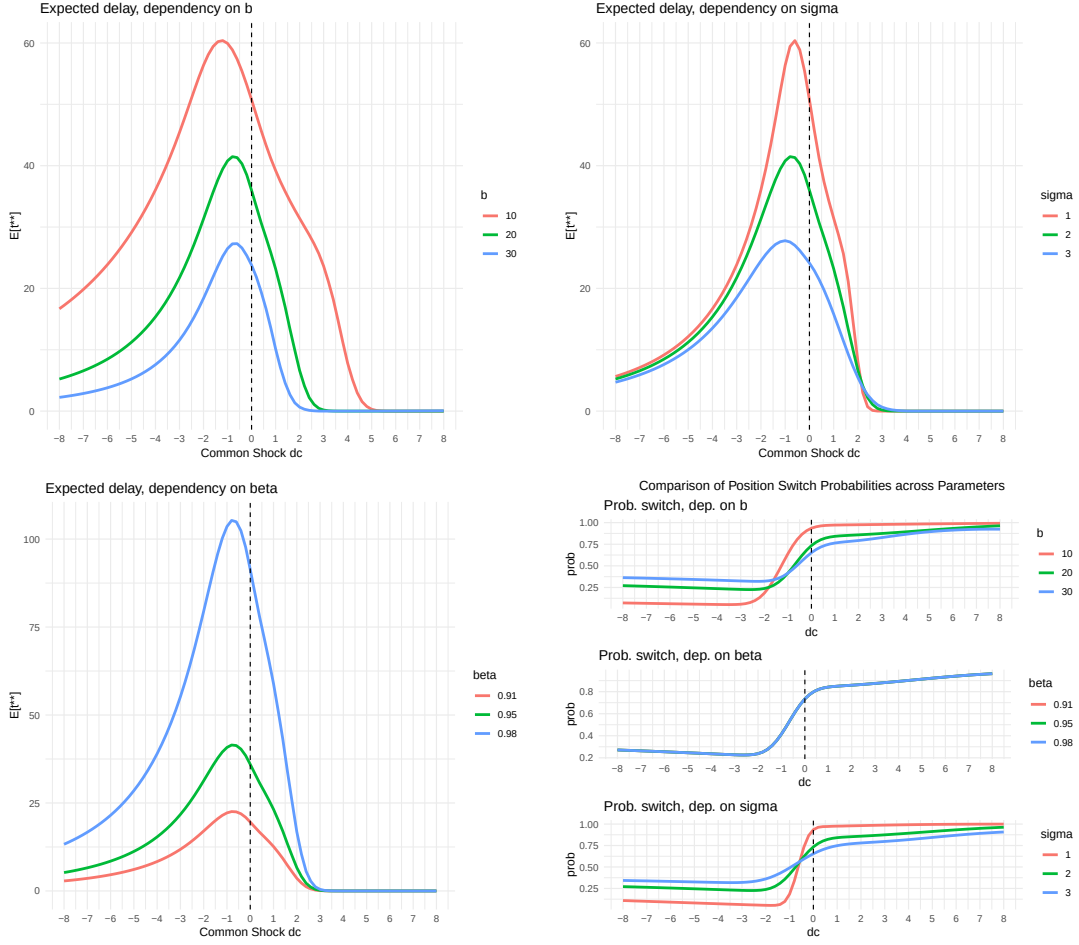


Figure 4: Expected delay times $E[t^{**}]$ and expected leadership switches

asymmetries of estimated hazard functions which suggest that price increases are more likely than price declines (Luo and Villar (2021)). Cost declines improve profits even in the uncomfortable “waiting” position for both rivals, thus leading to willingness to delay adjustment. As we will see later, this asymmetry is even more pronounced for the case of iso-elastic demand.

(c) The larger the parameter b and thus the substitutability of the goods are, the lower are the expected delays. This implies different degrees of stickiness across industries which supply goods with different substitution elasticities, and might thus help explaining the substantial cross-industry variation in price adjustment dynamics (Dias et al. (2015), Gwin (2009), Klenow and Malin (2010)).

(d) The larger the discount factor β , the longer is the expected delay. Also this is according to intuition: larger β indicates more patience as beneficial future profits from the follower position are less discounted. To my knowledge, a direct empirical relationship between inflation inertia and the time preference is not yet investigated.

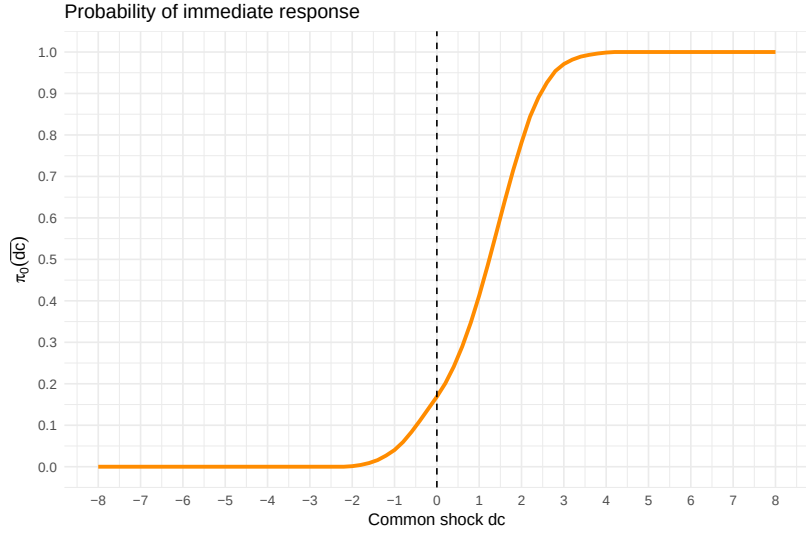


Figure 5: Probability of immediate response: $E\pi^{BR} \leq E\pi^L$

Falk et al. (2018) provide a comprehensive cross-country survey of patience data which could be associated with β values. In chapter 3, I will argue that $\beta = e^{-(\rho+\delta)\Delta}$ with Δ as a calendar time measure and δ as a Poisson rate for a shock arrival process. Differences in β are thus due to different time preference rates, but (more realistically) also due to differences of the intensity of shock processes, e.g. crises times vs. normal times.

(e) The expected delay times decline if the variance of the idiosyncratic shocks increases. This is mainly because a larger portion of the probability mass lies outside of $\mathcal{G}_1$ or $\mathcal{G}_2$ so that there is no rivalry for the follower position and hence no reason for strategic delay (see fig. 3). But this also means that for the case of pure common shocks ($\sigma^2 = 0$) we have a quite large expected delay. This clearly shows that strategic delay, in this model, does not have anything to do with information asymmetry like in Admati and Perry (1987) or Larson (2016).

But there is a further interesting implication of the model: using figure 3, we define a flag which is one if the leader-follower positions switch after a shock, and zero if previous positions prevail. Integrating over all combinations of idiosyncratic shocks, we obtain the estimated probability of a switch, depending on the common shock $\bar{dc}$. The qualitative picture is the same for different parameterizations we considered in figure 4, therefore I plot the estimated probability of position switches for all parametrizations in figure 4, bottom right panel. The stylized model result (f) is that changes in the leadership position are much more likely in case of cost (and thus price) increases, while in case of price declines it is more likely that Stackelberg positions prevail. For very small shocks, the results are ambiguous. There are only few empirical studies on

price leadership changes; the results from [Seaton and Waterson \(2013\)](#) point into the direction suggested by this model.

To sum up, the model of strategic delay is capable to explain a large variety of empirically relevant price adjustment asymmetries without relying on nominal frictions. As the profits in a particular Stackelberg position are the same for both (symmetric) firms, the results regarding delay signals t_i^* stem from the different impact of the shock on the profits in the waiting position and thus the chance of winning the war of attrition. Hence, the strategic delay mechanism successfully propagates the dispersed price setting after each shock which enables higher markups than in the Bertrand-Nash solution. Due to the asymmetry between positive and negative shocks, we have additionally a temporary markup boost due to the “collusion-like” delay in case of cost declines which are temporarily not transmitted to the consumers.

2.4 Iso-elastic demand function

Although a Stackelberg duopoly with linear demand and constant marginal cost is a quite trivial model for undergraduates, the computation of $E[t^{**}]$ requires to integrate the probability-weighted delay times on the set $\mathcal{F}$ of all idiosyncratic shock configurations, separately for each common shock. Things become much more computationally expensive when considering an iso-elastic demand function of the form

$$q_i = \frac{Y}{P} \left(\frac{p_i}{P} \right)^{-\theta}, \quad \text{with } P = \left(\sum_{j=1}^n p_j^{1-\theta} \right)^{\frac{1}{1-\theta}} \quad (4)$$

with $\theta > 1$. The FOC of maximizing $\pi_i = (p_i - c_i)q_i$ is not polynomial in the prices so that we do not have a closed form of the best response function $p_i = BR(p_{-i})$. Thus, we cannot analytically determine a Stackelberg equilibrium. Therefore, to my knowledge, all macroeconomic models which consider the case of a heterogeneous oligopoly with iso-elastic demand, are interested in the *symmetric* Bertrand-Nash solution which is easy to determine analytically (like in [Wang and Werning \(2022\)](#), [Etro and Rossi \(2015\)](#) and [Etro and Colciago \(2010\)](#), for example). In the model at hand, however, this is not an option.

For the case of iso-elastic demand, we calculate a second order Taylor approximation of the (numerically specified) profit function at the symmetric Bertrand-Nash solution in order to obtain linearized best response functions. This allows then for an approximate Stackelberg solution. Afterwards, we repeat the procedure by approximating the profit function at the proxy Stackelberg solution and so on. For a good approximation of the Stackelberg solution the slope of the rival’s best response function and the slope of the firm’s iso-profit curve should be nearly identical. After some

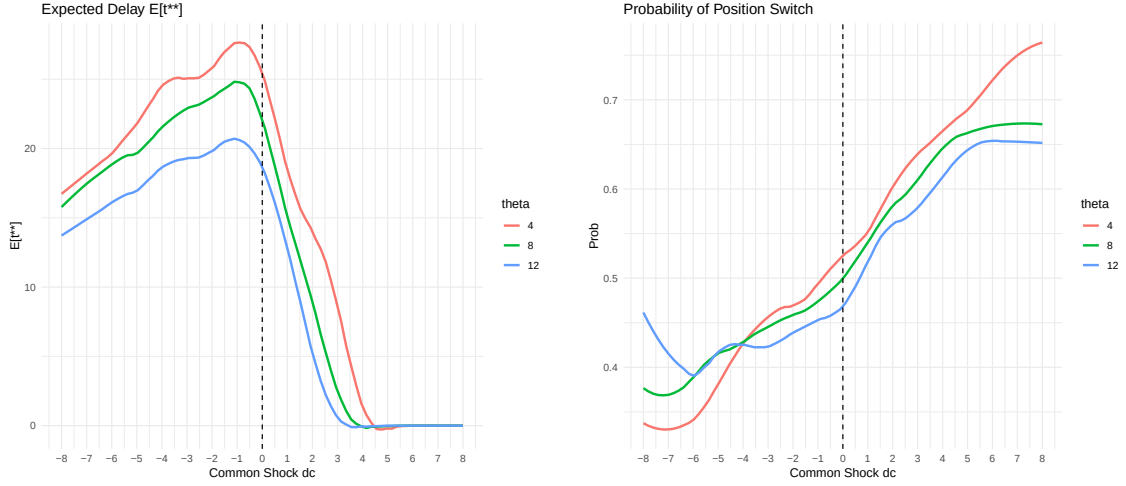


Figure 6: Expected delays and leadership switches in case of iso-elastic demand function

iterations of the approximation procedure described above, we obtain the Stackelberg solution with quite high precision. This needs to be done for each set of idiosyncratic shocks (dc_1, dc_2) for each given common shock $\bar{dc}$, separately for both firms which have to form *expected* profits for the cases of being in the leader, the follower, or in the waiting position. As we do not have analytical expressions of the profit functions, we do not use eq. (1) for calculating expected profits but using the first order Taylor approximation only. With the given numerical examples, the resulting Jensen error is very small so that we neglect it.

It turns out that the expected delay times $E[t^{**}]$ qualitatively show a similar pattern as in the linear case. Figure 6 shows the dependency on the elasticity θ : the higher the elasticity, the lower is the expected delay². Compared to the linear demand function, the asymmetry regarding positive and negative shocks is even more pronounced. Also the result that switches in the leader-follower position are likely for positive shocks but unlikely for negative ones, prevails for the case of iso-elastic curves (right panel of fig. 6). However, the change of likelihood of such switches is more smooth for small shocks than in the linear demand case.

2.5 Sector-specific shocks

Consider that the economy consists of s different sectors which are exposed to the common shock $\bar{dc}$ but also a sector-specific shock dc_s . In the following we abstract from firm-specific idiosyncratic shocks for sake of simplicity. As the sector-specific shock is common knowledge to all firms of this sector, we can drop the expectation

²Same parameterization as in the linear baseline model, except for replacing b by θ .

operator, and delay signals t_i^* are common knowledge. Assuming $dc_s \sim \mathcal{N}(0, \sigma^2)$, and zero covariance, we can re-label $E[t^{**}]$ as the expected delay across all industries. Correspondingly, the CDF $F(t) = \pi_0 \mathbf{1}(t \geq 0) + (1 - \pi_0) \Gamma(t > 0)$ can be interpreted as the time-dependent *share* of industries which have adjusted to the Stackelberg reset price in period t after the shock. This is the counterpart of the Calvo parameter where we have a fixed Poisson arrival rate. Taking the baseline parametrization of the model with iso-elastic demand scheme, except for switching off the firm-specific idiosyncratic shocks, and assuming $\sigma = 3$ for sector-specific shocks, the expected delay times across industries, and also the probability of immediate switch to reset prices are shown in figure 7.

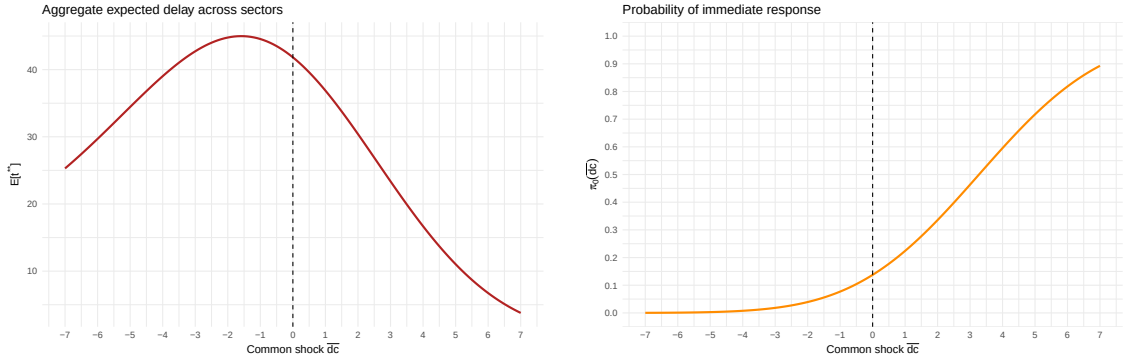


Figure 7: Sector-specific shocks: expected delays and probability of no delay

Figure 8 shows the model-based and approximated CDFs for a positive common shock $\bar{dc} = +10\%$ (left) and a negative cost shock $\bar{dc} = -15\%$ (right). In the former case, 33.5% of the sectors adjust immediately to the reset price, while in the latter case there is nearly no immediate response. As explained in the previous section, large positive cost shocks make it more likely that any first mover prefers to achieve a quick Stackelberg arrangement rather than playing best response to rival's stale prices. Hence, in these cases strategic delay is not reasonable. So there is not just an asymmetry regarding large vs. small shocks, but in particular positive large vs. negative large shocks. For very large positive shocks there is much less evidence for stickiness (Cavallo et al. (2024)). Also Gagliardone et al. (2025) report that nonlinearities of cost-passthrough in the Phillips Curve kick in for large positive cost shocks. These observations are in line with the present model of strategic delay. In the next chapter, when discussing aggregated price dynamics, I will refer to the model with sector-specific shocks and CES demand function.

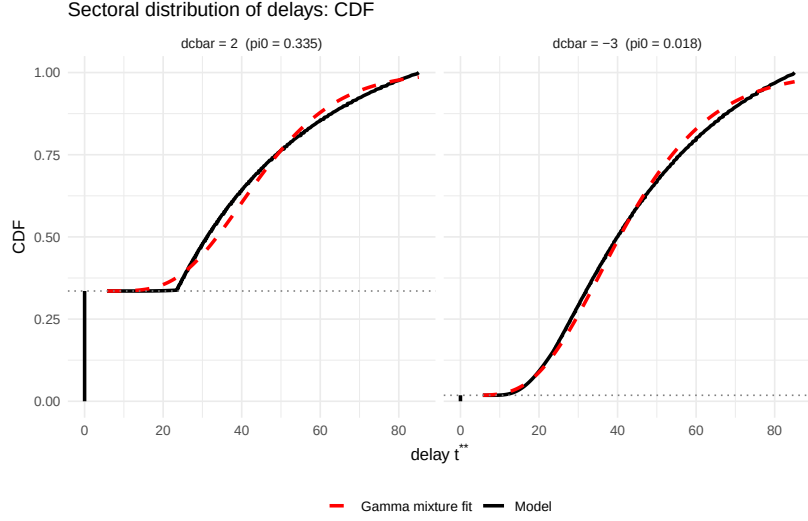


Figure 8: Sector-specific shocks: CDFs of positive and negative shock

2.6 The case of $n > 2$ firms

With an increasing number of firms, strategic complementarity declines, the Bertrand-Nash solution converges to a (monopolistic) competitive outcome (Vives (1985)). The reason is the weakening of the strategic complementarity as expressed by the slope of best response functions as pointed out by Wang and Werning (2022). For the linear demand case this is straightforward. For the iso-elastic demand scheme, denote the price index $P = (p_i^{1-\theta} + (n-1)\tilde{p}^{1-\theta})^{\frac{1}{1-\theta}}$ with $\tilde{p}$ as an *aggregate* of all rival prices, following the idea of aggregative games (Acemoglu and Jensen (2013)). Given the iso-elastic demand scheme, let $p_i = g(\tilde{p})$ denote the best response to the aggregate rival's price. The response to an individual rival's price is thus

$$\frac{\partial p_i}{\partial p_j} = \frac{1}{n-1} \frac{dg(\tilde{p})}{d\tilde{p}} \quad \text{which is} \quad \left. \frac{\partial p_i}{\partial p_j} \right|_{\text{Nash}} = \frac{\theta - 1}{n(n-1)\theta} = B \quad (5)$$

when all firms set Bertrand-Nash prices. As mentioned before, we cannot analytically derive a best response function $g(\tilde{p})$ from the FOC, but we can compute eq. (5) from the total derivative of the FOC in the Bertrand-Nash solution. Expression B indicates that with increasing n , the strategic complementarity declines. The flatter the best response functions, the closer the tangential point with rival's iso-profit curve must be to the Bertrand-Nash solution. Hence, the dispersion of Stackelberg prices declines and the average Stackelberg price gets closer to the Bertrand-Nash price with increasing n , while the latter converges to the monopolistic-competitive price. Doing the same exercise with a linear demand scheme where the price index is $P = \frac{p_i + (n-1)\tilde{p}}{n}$,

we obtain

$$\left. \frac{\partial p_i}{\partial p_j} \right|_{\text{Nash}} = \frac{1}{2(n-1)} = \tilde{B}$$

which also shows a negative dependency on n .

This has consequences for the delay times. The maximum delay time t_i^* according to eq. (3) is based on the relation of $(E\pi_i^W - E\pi_i^L)/(E\pi_i^W - E\pi_i^F)$. Hence, this relation converges to one for large n as $E\pi_i^F$ converges to $E\pi_i^L$, and thus the maximum delay time converges to zero. This perfectly makes sense, as for large n , the follower position is no longer so much better than the leader position. It is less worth to fight for it in a war of attrition.

Proposition 2: Given a n -firm oligopoly, and assumptions (A.1) hold true. Given the concession times $t_1^* < t_2^* < \dots < t_n^*$ and thus a delay $t^{**} = t_{n-1}^*$ when the last follower will adjust the price and thus a full Stackelberg equilibrium is established. It is t^{**} converges to zero as $n \rightarrow \infty$.

Proof: Define $\tilde{p}_{-i}$ as an aggregate of the rival's prices, so that

$$\frac{\partial p_i}{\partial p_j} = \frac{1}{n-1} \frac{\partial p_i}{\partial \tilde{p}_{-i}}$$

is the slope of i 's average best response to a rival j which depends negatively and monotonously on n . The flatter the slope of the best response function, the closer the Stackelberg solution is to the (symmetric) Nash solution, implying declining differences between leader and follower profits. The slope converges to zero with increasing n . As the first order condition of a player on stage $k \in \{1, 2, \dots, n\}$ is

$$\frac{d\pi_k}{dp_k} = \frac{\partial \pi_k}{\partial p_k} + \sum_{j>k} \frac{\partial \pi_k}{\partial p_j} \frac{\partial p_j}{\partial p_k} = 0$$

the sum converges to zero. Hence the FOC become identical to the Bertrand-Nash case. As this holds true for any stage, the outcomes $E\pi^F$ and $E\pi^L$ will converge, too. Hence, the argument of the log expression in eq. (3),

$$\frac{E\pi^W - E\pi^L}{E\pi^W - E\pi^F} = 1 + \frac{E\pi^F - E\pi^L}{E\pi^W - E\pi^F}$$

converges to 1, as the r.h.s. numerator converges to zero while the r.h.s. denominator will always stays a non-zero number. This results in $t_i^* \rightarrow 0$ for any i . $\square$

This convergence to zero is *monotone* if $E\pi^F - E\pi^L$ converges faster than $E\pi^W - E\pi^F$ which is numerically the case for linear demand. Here expected delay times $E[t^{**}]$ shrink quite quickly with n . As a consequence, the idea of strategically delayed price adjustment might be convincing in principle, but it will have a negligible impact once

when n is moderate or even large. Hence, one can question its role as an alternative to friction-based models such like Calvo, if n is large. However, as briefly discussed below, an alternative assumption is a market structure which is characterized by few dominant firms, engaged in Stackelberg oligopoly, and fringe firms which sets prices as if being under monopolistic competition due to their low market power (Cherry (2000), Tasnádi (2000)). The idea of fringe firms draws back to Stackelberg himself (see Etro (2014)). The rise of few powerful firms with large market shares while the majority of rival firms remain small, also seems to be an empirically relevant phenomenon which is consistent with high and dispersed markups, and skewed firm size distribution (De Loecker et al. (2020), Autor et al. (2020)). Such market forms – oligopoly plus fringe – enjoy growing importance also in endogenous innovation and growth models (see e.g. Acemoglu (2023), Cavenaile et al. (2022)).

In absence of frictions, the fringe would always respond to a shock immediately while few dominant firms exhibit strategic delay. Consider, for example, a market with n firms where $(n - 2)$ firms are a fringe, and we have one leader and one follower (duopoly plus fringe). The fringe firms set their price simultaneously in a monopolistic-competitive manner. The idea of leader-follower structures in price competition is that prices and markups are larger than in Bertrand-Nash or in a competitive solution. When firms are symmetric, this leads to a contradiction: fringe firms have lower prices but at the same time a low market share. Hence we need to allow for some *cost heterogeneity* and thus relaxing the assumption of symmetry of firms. As a result, the market form of heterogeneous oligopoly plus some clustering of firms – a block of many similar firms with lower productivity, small market shares and thus non-strategic behavior, and few more productive firms which are strategic price-setters with markups above the monopolistic-competitive level – is even “more generic” than just an oligopoly with symmetric firms. And it is also closer to the empirical picture that average markups have grown significantly in the recent decades while the median markup was more or less stable. This indicates that there is more market power in the upper tail in the distribution which means: few firms became more dominant and have higher markups compared to the rest (De Loecker et al. (2020)), and firm size distribution is highly skewed (Sutton (2007)).

Therefore, we relax the symmetry assumption and consider, instead, that the majority of (fringe) firms have cost c_f which are higher than the cost of oligopolistic (for sake of simplicity: duopoly) firms: $c < c_f$. As factor prices are the same for all, the cost advantage can be seen as a result of higher productivity or a different optimal combination of input factors (e.g. capital intensity). A simple way to establish a price index such that the fringe has a constant market share is to assume a fringe whose market share is then split up to $(n - 2)$ single firms. The price level which enters the

duopolist's profit function is

$$P = (P_F^{1-\theta} + P_L^{1-\theta} + \xi P_{fr}^{1-\theta})^{\frac{1}{1-\theta}} \quad (6)$$

where ξ reflects the relative influence of the fringe's price P_{fr} on the price level as the fringe represents several firms with a limited market share. As each fringe firm charges the monopolistic competitive price, independent of n , the calculus of the duopolists (or in general: dominant firms) does no longer depend on n . The result is that Stackelberg profits and expected delay times do not at all depend on the number of fringes, but only on the *number of dominant firms*.

With these assumptions about the underlying market structure – few firms in leader-follower structure plus a block of non-strategic fringe firms – the model predicts, adding point (g) to the list of stylized results from section 2.3, an increase of expected delay times if less firms are strategically important players, or in other words: having more concentration and market power at the upper tail of firm size distribution. This is in line with empirical findings such like [Dias et al. \(2015\)](#) who find more price stickiness for large than for small firms. The nexus between market power and delay has the same root as in [Wang and Werning \(2022\)](#), namely the degree of strategic complementarity, but is based on a different transmission mechanism without frictions.

3 Aggregated price dynamics

For the case of one industry, we have seen that – due to the distribution of sector-specific shocks – positive delay times are approximately distributed by the CDF $F(t) = \pi_0 \mathbf{1}(t \geq 0) + (1 - \pi_0) \Gamma(t > 0)$ where π_0 is the probability of immediate response. If we consider a continuum of (structurally identical) industries, all exposed to the same shock, we can interpret $F(t)$ as the *share* of industries which have adjusted to the new reset price P^* , comparable to the Poisson arrival rates in the Calvo model. While in the Calvo model we have a constant share ϕ of non-adjusting firms in a sector with monopolistic competition, the price level is given by $P_t = ((1 - \phi)(P_t^*)^{1-\theta} + \phi P_{t-1}^{1-\theta})^{\frac{1}{1-\theta}}$ from which we can derive the approximation $\pi_t = (1 - \phi)(p_t^* - p_{t-1})$ with p_t^* as the reset log price after a shock, and p_{t-1} as the log price of the previous period. The goal is to derive a corresponding law of motion for the inflation rate for the strategic delay model.

Consider that in each industry there is a fringe firm with a relative weight ξ within the price index, and a duopoly which arranges a Stackelberg equilibrium after some strategic delay. The CES price aggregate is a weighted combination of fringe prices as well as Stackelberg prices in industries which have adjusted already to the reset

prices, and the transitory prices of industries where we still have strategic delay, both weighted with the corresponding shares:

$$\begin{aligned}
P(t) &= \underbrace{[\xi(P_{fr}^*)^{1-\theta}]}_{\text{fringe}} + \underbrace{[\pi_0 + (1 - \pi_0)\Gamma(t)]}_{F(t)} ((P_L^*)^{1-\theta} + (P_F^*)^{1-\theta}) \\
&\quad + \underbrace{(1 - \pi_0)(1 - \Gamma(t))}_{1-F(t)} (p_{BR}^{1-\theta} + p_S^{1-\theta})^{\frac{1}{1-\theta}} \\
&= [(1 - F(t))P_T^{1-\theta} + F(t)(P^*)^{1-\theta}]^{\frac{1}{1-\theta}}
\end{aligned} \tag{7}$$

with $P^* = [\xi(P_{fr}^*)^{1-\theta} + (p_L^*)^{1-\theta} + (p_F^*)^{1-\theta}]^{\frac{1}{1-\theta}}$ as the reset price level, and $P_T = [\xi(P_{fr}^*)^{1-\theta} + P_{BR}^{1-\theta} + P_S^{1-\theta}]^{\frac{1}{1-\theta}}$ as the transitory price level during strategic delay, where the upper index * indicates reset prices. Log-linearisation of (7) gives

$$p(t) \approx p_T + (p^* - p_T)F(t) \tag{8}$$

Equation (8) treats the reset gap as identical across sectors. With sector-specific shocks, $F(t)$ remains the share of adjusted sectors, but it is only an approximation of price-level pass-through, because the size of a sector's gap and its delay are related through the single-peaked delay function. The direction of the error depends on the common shock and the dispersion of sector shocks. With $\Gamma(t) \rightarrow 1$, we obtain the full reset price level. This is the analogue to the [Calvo \(1983\)](#) approach, except for the Dirac element in $F(t)$, reflecting that a certain portion of firms might adjust immediately. In continuous time, inflation rates are usually obtained by differentiation of $p(t)$. This is problematic due to the Dirac element in $F(t)$ which causes a certain jump of inflation in $t = 0$ immediately after the shock. Hence we switch to differences of log variables. Define $p_t = p(t)$, $F_t = F(t)$ and $S_t = 1 - F_t$ as the “survival share” of firms which have not yet adjusted to the reset price. Re-writing (8)

$$p_t \approx p_T + (p^* - p_T)(1 - S_t) = p^* - (p^* - p_T)S_t$$

so that $p^* - p_t = (p^* - p_T)S_t$, it follows

$$\pi_t = p_t - p_{t-1} = (p^* - p_T)(S_{t-1} - S_t) = (p^* - p_T)S_{t-1} \frac{S_{t-1} - S_t}{S_{t-1}} \tag{9}$$

substituting for $p^* - p_{t-1}$

$$\pi_t = (p^* - p_{t-1})h_t \quad (10)$$

with $h_t = \frac{S_{t-1} - S_t}{S_{t-1}}$ as the hazard rate in t . Equation (10) is the direct equivalent to the Calvo (1983) formulation except for that the fixed Calvo parameter is substituted by a time-dependent hazard rate which depends also on size and direction of the shock, among other determinants (see Caballero and Engel (1993) for hazard rate based price adjustment models). Thus, the Calvo model can be seen as an edge case. However, this paper addresses the evolution of price level and inflation rate as a response to a single shock, not a shock *process*. Hence, unlike Calvo, there is still a long way to obtain a Phillips Curve. For a shock process one has to consider that a new shock is likely to arrive when firms have not yet reached the full reset price level, hence there are some “reset gaps” Δ_s when a new shock arrives at time s . Hence, the inflation rate in t is a superposition of cumulated reset gaps. This points into the direction of hazard-based Phillips Curves (Whelan (2007), Sheedy (2010)).

As an illustration, I use the sector-based model from section 2.5 and the two shocks displayed in figure 8. Figure 9 shows the corresponding evolution of the aggregate pass-through $F(t) = (p_t - p_T)/(p^* - p_T)$ (upper panel) which is here defined as the share of fully adjusted industries rather than p_t/p^* . For sake of simplicity, no fringe is considered ($\xi = 0$). After a shock, we see an immediate jump of the price level, depending on the share of firms which adjust immediately without delaying. For $\bar{dc} = -15\%$ (right) this share is nearly zero (1.8%) while it is 33.5% in case of a positive 10% cost shock (left). The horizontal 50% line shows when half of the full reset price level is reached. The bottom panel shows the corresponding period-by-period inflation rates for the two shocks. Here, I have excluded the initial jump, so the path depicts only the adjustment dynamic for $t > 1$. Therefore, the inflation dynamic for the positive cost shock is less pronounced as about one third of the sectors absorbed the shock immediately in $t = 1$. Figure 10 plots the half-life criterion against the expected delay time $E[t^{**}]$. One can see that for a sufficiently large positive cost shock ($\bar{dc} \approx 3.2$) the half-life of absorption drops to zero which matches with the right side of figure 7: the probability of immediate response is 50% in one sector translates into a 50% share of sectors which have adjusted already.

So far, the physical length of a model period has been left open. It is related to the discount factor which was set to $\beta = 0.95$ in all baseline simulations. All simulations investigate the dynamics of price adaption as a response to a *single* shock. However, firms are exposed to a shock process. New shocks will arrive, and any leader-follower arrangement lasts only until the next shock re-opens a new war of attrition.

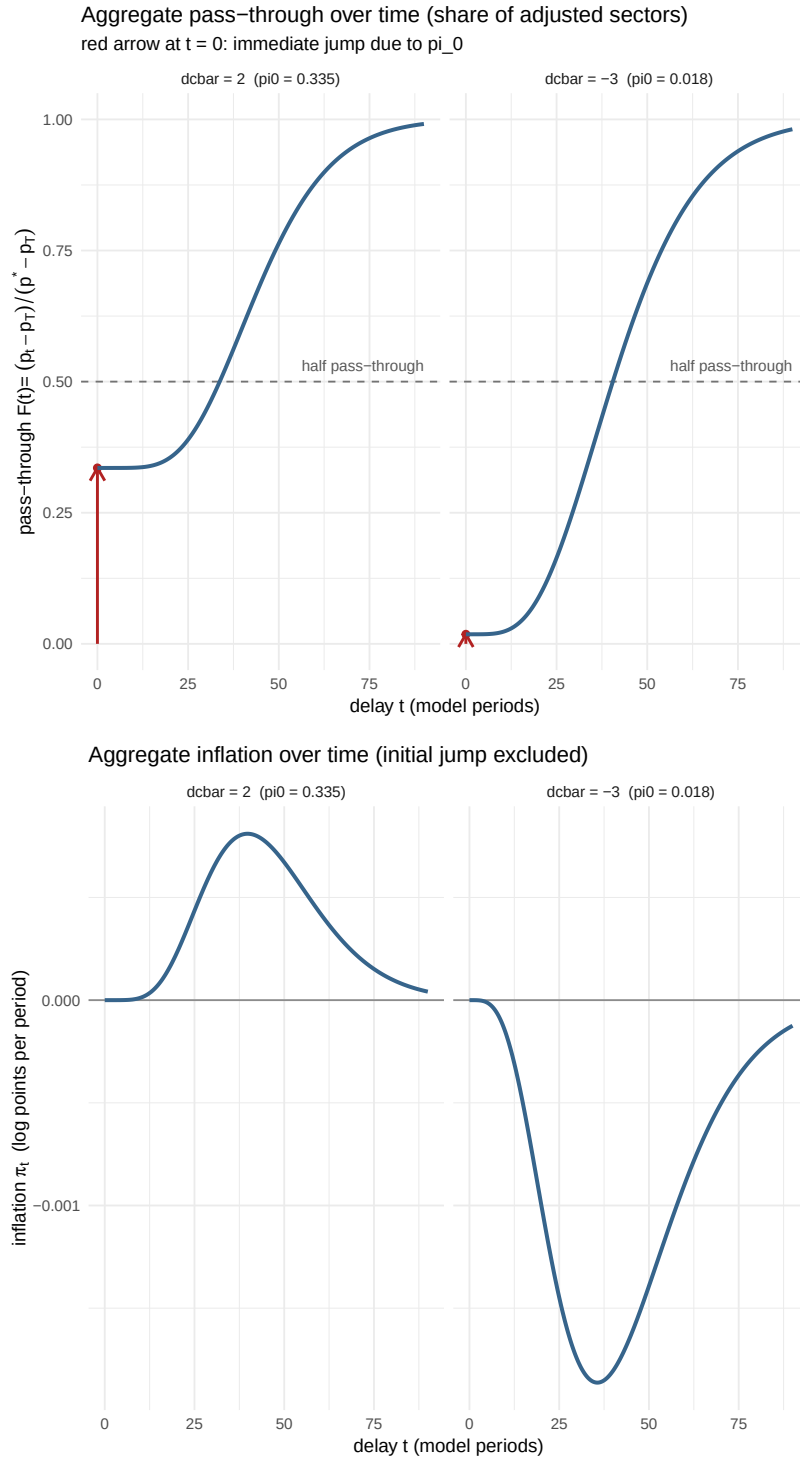


Figure 9: Pass-through and inflation dynamics for a positive and a negative shock ($\xi = 0$)

New shocks can arrive even before the full reset price after the last shock has been achieved. Let such shocks arrive according to a Poisson process with rate δ , so that the time until the next shock is exponentially distributed with mean $1/\delta$, and a given

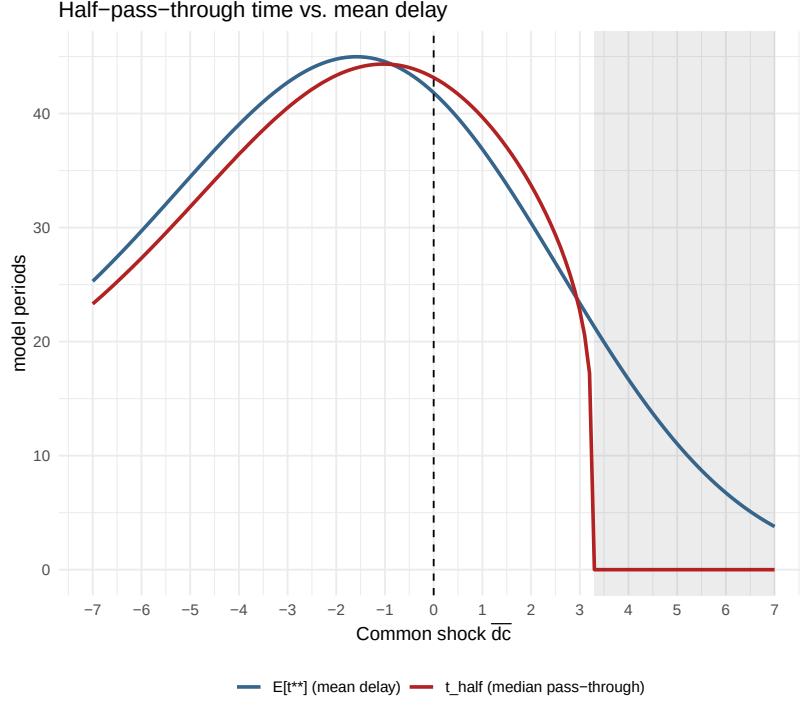


Figure 10: Pass-through vs. expected delay

position in the strategic interaction survives until t with probability $e^{-\delta t}$. Therefore, the expected net present value of a profit flow π is $\int_0^\infty e^{-(\rho+\delta)t} \pi dt$ where ρ is the time preference rate. Assuming that the continuation value after the next shock does not depend on the position held before, it cancels from both sides of eq. (2), and the concession condition holds with the *effective* discount factor

$$\beta = e^{-(\rho+\delta)\Delta},$$

where $\Delta = -\ln \beta / (\rho + \delta)$ the calendar length of a model period which is assumed to be a calendar week.

The arrival rate δ can be related to micro evidence on price setting. Regular price changes occur with a median monthly frequency of 9 – 12% in the US (Nakamura and Steinsson, 2008) and of about 12% in the euro area (Gautier et al., 2024), implying $\delta \approx 1.1 - 1.5$ p.a., implying that a new shock arrives every 8 – 11 months on average. Including temporary sales, the US median frequency is about 20% which implies $\delta \approx 2.7$ p.a. With $\rho = 0.04$, a model period of one week then corresponds to β between 0.98 and 0.95, consistent with the value used in the baseline simulations. As each shock triggers at least one price change per firm, observed frequencies tend to overstate δ , so that $\beta = 0.95$ marks the lower end of this range.

A final exercise is to relate prices to marginal cost. Let μ be the *average* markup in the Stackelberg duopoly. For sake of simplicity, assume that the first mover who plays best response against the stale price of the delaying firm has the same markup μ . The fringe firms, deciding under monopolistic competition, will have a lower markup, $\mu_f < \mu$. Let MC_1 be the marginal cost after the shock, and MC_0 prior to the shock. To keep notation simple, define

$$A = [(1 + \mu_f)MC_1]^{1-\theta}, \quad M_0 = [(1 + \mu)MC_0]^{1-\theta}, \quad M_1 = [(1 + \mu)MC_1]^{1-\theta}$$

Hence we have the price levels

$$(P^*)^{1-\theta} = \xi A + 2M_1, \quad P_T^{1-\theta} = \xi A + M_1 + M_0$$

As A and M_1 depend on the same marginal cost, we have the ratio

$$\frac{A}{M_1} = \left(\frac{1 + \mu_f}{1 + \mu} \right)^{1-\theta} = \kappa$$

Log-linearizing then yields

$$p^* - p_T = \frac{1}{2 + \xi\kappa} \ln \left(\frac{MC_1}{MC_0} \right) \quad (11)$$

and thus

$$\pi_t = \frac{1}{2 + \xi\kappa} \widehat{MC}(F_t - F_{t-1}) \quad (12)$$

with $\widehat{MC} = \ln(MC_1/MC_0)$ as the percentage marginal cost change. The equation holds for $t > 1$, while in the period immediately after the shock, inflation is determined by the immediately adjusting firms only. For $t = 1$ we need to compare the price level with the pre-shock level $P_{pre}^{1-\theta} = M_0(\xi\kappa + 2)$. Hence

$$p_T - p_{pre} \approx \frac{1 + \xi\kappa}{2 + \xi\kappa} \widehat{MC}$$

the transitory percentage price change. As the difference between equilibrium price prior to shock and full reset price is $p^* - p_{pre} = \widehat{MC}$, we can decompose $p^* - p_{pre}$ into

$$\frac{1 + \xi\kappa + \pi_0}{2 + \xi\kappa} \widehat{MC} \quad + \quad \frac{1 - \pi_0}{2 + \xi\kappa} \widehat{MC}$$

where the first term applies only in $t = 1$ immediately after the shock. The cost pass-through in time, governed by Γ , applies only to the second term.

4 Concluding remarks

This paper has demonstrated that nominal rigidities – a central tenet of modern macroeconomics – can be fundamentally understood as an equilibrium outcome of strategic interaction rather than a mere consequence of exogenous frictions. By moving beyond the conventional reliance on menu costs or Calvo-type arrival rates, I have provided a microfoundation where price stickiness and staggered adjustment emerge from the rational, strategic calculus of firms in an oligopolistic environment. The core contribution of this research lies in the endogenous determination of the timing of price adjustments. I show that firms utilize their price flexibility to strategically signal their entry into a sequential Stackelberg structure. This delay is not a sign of inefficiency or “stickiness” in the traditional sense, but a tool for maximizing the net present value of profits by establishing a more favorable market position. The model accounts for stylized empirical facts that standard models struggle to explain simultaneously and without frictions, adjustment cost or trend inflation: the inherent asymmetry in the response to shock direction (positive vs. negative) and shock magnitude (small vs. large), as well as the impact of market concentration and price elasticity on the speed of adjustment. Furthermore, by aggregating these industry-level strategic delays into a macroeconomic framework, I have shown that a continuum of such oligopolistic sectors leads to an aggregate price index which can be approximated by Gamma-distributed dynamics. This bridge between IO-based strategic timing and macroeconomic price sluggishness suggests that the Calvo parameter often used in DSGE models is not a structural constant but a function of market power and the nature of the underlying shocks.

While this framework offers a novel perspective on nominal rigidities, several limitations remain which define the path for future research. First, most of the results have been derived from the case of a linear demand structure and constant marginal costs. Iso-elastic demand schemes do not have analytical closed-form solutions, and are computationally demanding. Second, it remains a partial equilibrium analysis within a continuum of sectors. A significant desideratum for future work is the integration of this strategic timing mechanism into a full General Equilibrium framework to evaluate its impact on the slope of the Phillips Curve and the transmission of monetary policy. Third, the analysis is about adaption dynamics for a single shock rather than a shock process. A promising avenue for research is the empirical exploration of the proposed aggregate dynamics. The parameters of the Gamma distribution governing price adjustment could be treated as endogenous functions of market characteristics. A structural empirical strategy could be used to regress these parameters on measures of industry concentration and shock volatility. Finally, exploring the implications of this model for “sticky-information” versus “sticky-price” debates would be fruitful, partic-

ularly regarding how strategic delays interact with the rate of information diffusion among firms.

Ultimately, this paper suggests a shift in the macroeconomic narrative: the view that a frictionless and seamless Arrow-Debreu world is the benchmark, and only some sort of distortive ad hoc deviations from it lead to Keynesian features, is challenged. Instead, a world with *heterogeneity* and *strategically* acting firms, keeping neoclassical assumptions of rationality and price flexibility intact, is the *more general case* which implies already Keynesian features.

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Appendix

With the linear demand scheme given in the text, one can easily compute the expected profits $E\pi^F, E\pi^L, E\pi^W$ for a duopoly, using eq. (1) which is exact in the linear case. As the waiting profits depend on the prior price (leader or follower), we obtain two critical values t_i^* from equation (3). Without loss of generality, assume that $i = 1$ is the former follower, and $i = 2$ is the former leader.

$$t_1^* = \frac{\ln \left(\frac{8y^2 + (8\bar{d}c + 6dc_1)by + 3b^2\sigma^2 + (16\bar{d}c^2 + 16dc_1\bar{d}c + 3dc_1^2)b^2}{15y^2 + (8\bar{d}c + 8dc_1)by + 2b^2\sigma^2 + (16\bar{d}c^2 + 16dc_1\bar{d}c + 2dc_1^2)b^2} \right)}{\ln \beta}$$

$$t_2^* = \frac{\ln \left(\frac{7y^2 + 2dc_2by + 3b^2\sigma^2 + (16\bar{d}c^2 + 16dc_2\bar{d}c + 3dc_2^2)b^2}{14y^2 + 4dc_2by + 2b^2\sigma^2 + (16\bar{d}c^2 + 16dc_2\bar{d}c + 2dc_2^2)b^2} \right)}{\ln \beta}$$

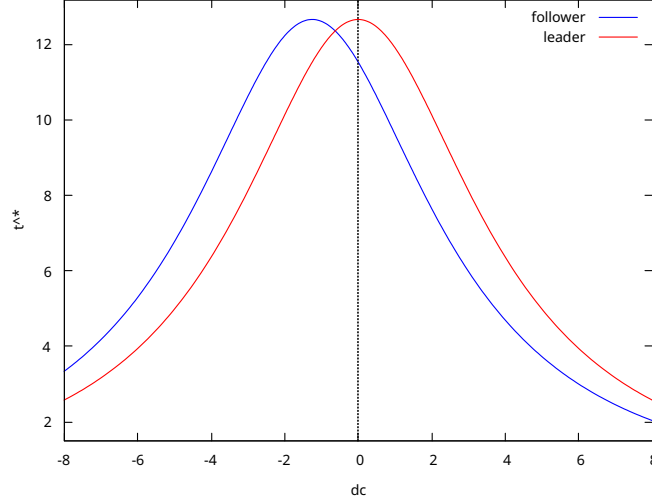


Figure 11: Delays t_1^*, t_2^* without idiosyncratic shocks

In absence of idiosyncratic shocks ($dc_1 = dc_2 = 0$), one can directly see that these delays are single-peaked in the common shock $\bar{d}c$, and the peak is for $\bar{d}c \leq 0$:

$$\begin{aligned} \frac{\partial t_1^*}{\partial \bar{d}c} = 0 & \Rightarrow \bar{d}c = -\frac{y}{4b} \\ \frac{\partial t_2^*}{\partial \bar{d}c} = 0 & \Rightarrow \bar{d}c = 0 \end{aligned}$$

The entire function $t_2^*(\bar{d}c)$ is thus a shift $t_2^*(\bar{d}c) = t_1^*(\bar{d}c - y/4b)$, reflecting that both players in different prior Stackelberg positions are hit by the same shock in a different manner in the waiting position, or hit in the same manner by a different (“shifted”) shock. Further, the curves have a unique intersection point at $\bar{d}c = -y/8b$. Recall,

that $t^{**} = \min(t_1^*, t_2^*)$ (see figure 11). Hence, this explains the asymmetry between small and large shocks, and between positive and negative shocks, as well as the result that for positive shocks we observe more often a leadership switch (as here it is $t_1^* < t_2^*$), while for negative shocks the positions are often preserved (as here we have $t_1^* > t_2^*$).

One can calculate the partial derivatives of t_1^*, t_2^* with respect to b, σ, β for the case of $dc_1 = dc_2 = 0$. The signs of the derivatives confirm the results from section 2.3 where we computed expected delays with idiosyncratic shocks.