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A Theory of Price Adjustment under Loss Aversion^{*}

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Abstract

We present a new partial equilibrium theory of price adjustment, based on consumer loss aversion. In line with prospect theory, the consumers' perceived utility losses from price increases are weighted more heavily than the perceived utility gains from price decreases of equal magnitude. Price changes are evaluated relative to an endogenous reference price, which depends on the consumers' rational price expectations from the recent past. By implication, demand responses are more elastic for price increases than for price decreases and thus firms face a downward-sloping demand curve that is kinked at the consumers' reference price. Firms adjust their prices flexibly in response to variations in this demand curve, in the context of an otherwise standard dynamic neoclassical model of monopolistic competition. The resulting theory of price adjustment is starkly at variance with past theories. We find that - in line with the empirical evidence - prices are more sluggish upwards than downwards in response to temporary demand shocks, while they are more sluggish downwards than upwards in response to permanent demand shocks. The degree of these asymmetries, in turn, depends on the size of the shock.

Keywords: price sluggishness, loss aversion, state-dependent pricing

JEL classification: D03, D21, E31, E50.

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1. Introduction

This paper presents a theory of price sluggishness based on consumer loss aversion, along the lines of prospect theory (Kahneman and Tversky, 1979). The theory has some important, distinctive implications, which are starkly at variance with major existing theories of price adjustment. In particular, the theory implies that prices are more sluggish upwards than downwards in response to temporary demand shocks. By contrast, prices are more sluggish downwards than upwards in response to fully persistent, permanent demand shocks. The degree of these asymmetries, in turn, depends on the size of the shock.

These implications turn out to be consonant with recent empirical evidence. Though this evidence has not thus far attracted much explicit attention, it is clearly implicit in a range of influential empirical results. For instance, Hall et al. (2000) document that firms mostly accommodate negative temporary demand shifts by temporary price cuts, yet they are reluctant to temporarily increase their prices in response to positive temporary demand shifts. Furthermore, the empirical evidence provided by Kehoe and Midrigan (2008) indicates that temporary price reductions are - on average - larger and much more frequent than temporary price increases, implying that prices are relatively downward responsive.

By contrast, in the event of a permanent demand shock, the empirical evidence points towards a stronger upward flexibility of prices for a wide variety of industrialized countries (Kandil, 1995, 1996, 1998, 2001, 2002a,b, 2010; Weise, 1999; Karras 1996; Karras and Stokes 1999) as well as developing countries (Kandil, 1998).

Small demand shocks, in turn, are likely to have little effect on prices at all, whereas large demand shocks yield strong and asymmetric price responses (Kwapil et al., 2010; Weise, 1999).

Standard theories of price adjustment commonly applied in the New Keynesian literature fail to account for these empirical regularities. In particular, time-dependent models (e.g., Taylor, 1979; Calvo, 1983; Ball et al., 1988) imply symmetric price adjustment, whereas standard state-dependent models (e.g., Rotemberg, 1982) imply prices respond asymmetrically to small and large demand shocks, but generally symmetrically to positive and negative shocks. Hybrids of time- and state-dependent models successfully explain asymmetric responses to small and large and positive and negative shocks (e.g., Ball and Mankiw, 1994; Devereux and Siu, 2007), but these theories do not distinguish between temporary and permanent shocks and how this affects the asymmetry of the price response. Burstein (2006) explicitly studies temporary and permanent shocks in a state-dependent pricing model, but does not analyze the sign-based asymmetry characteristics of his model for permanent shocks and its interactions with the persistence of the shock. This paper, by contrast, offers a possible theoretical rationale consistent with all of the empirical regularities outlined above.

The basic idea underlying our theory is simple. Price increases are associated with utility losses for consumers, whereas price decreases are associated with utility gains. In the spirit of prospect theory, losses are weighted more heavily than gains of equal magnitude. Consequently, demand responses are more elastic to price increases than to

price decreases. The result is a kinked demand curve¹, for which the kink depends on the consumers' reference price. In the spirit of Kőszegi and Rabin (2006), we model the reference price as the consumers' rational price expectations. We assume that consumers know, with a one period lag, whether any given demand shock is temporary or permanent. Permanent shocks induce changes in the consumers' rational price expectations and thereby in their reference price, while temporary shocks do not.

When the demand shock is temporary, the kink of the demand curve implies that sufficiently small shocks do not affect the firm's price. This is the case of price rigidity. For larger shocks, the firm's price responds temporarily, but the size of the response is asymmetric for positive and negative shifts of equal magnitude. Since negative shocks move the firm along the relatively steep portion of the demand curve, prices decline more in response to negative shocks than in response to equiproportionate positive shocks.

By contrast, when the demand shock is permanent, the firm can foresee not only the change in demand following its immediate pricing decision, but also the resulting change in the consumers' reference price. A rise in the reference price raises the firms' long-run profits (since the reference price is located at the kink of the demand curve), whereas a fall in the reference price lowers long-run profits, a phenomenon which we term the reference-price updating effect. On this account, firms are averse to initiating permanent price reductions. By implication, prices are more sluggish downwards than upwards for permanent demand shocks.

We show that the phenomenon of "reversed asymmetry" - upward sluggishness of prices in response to temporary shocks and downward sluggishness of prices in response to permanent shocks - depends on the extent to which the reference price adjusts in response to price changes. Under adaptive, memory-based reference price determination, according to which the reference price is determined by an exponentially smoothed average of past prices (Briesch et al., 1997; Mazumdar et al., 2005), we find that prices are downward sluggish if the reference price adjusts quickly to permanent changes in demand, while prices are upward sluggish if the reference price responds only slowly.

The paper is structured as follows. Section 2 reviews the relevant literature. Section 3 presents our general model setup and in Section 4 we analyze the effects of various demand shocks on prices, both analytically and numerically. Section 5 concludes.

2. Relation to the Literature

In this section, we first consider the empirical evidence on asymmetric price adjustment, which our theoretical analysis aims to account for. Second, we discuss the contribution of this paper to the theoretical literature. Finally, we review empirical evidence underlying the behavioral assumptions of our theory.

¹Modeling price sluggishness by means of a kinked demand curve is of course a well-trodden path. Sweezy (1939) and Hall and Hitch (1939) modeled price rigidity in an oligopolistic framework along these lines. In these models, oligopolistic firms do not change their prices flexibly because of their expected asymmetric competitor's reactions to their pricing decisions. A game theoretic foundation of such model is presented by Maskin and Tirole (1988).

Recent years have witnessed a rapidly growing literature documenting a wide variety of business cycle asymmetries, especially in response to policy interventions on the demand side of the economy. There is a large literature showing that these asymmetries depend on, e.g., the sign (DeLong and Summers, 1988; Cover, 1992; Weise, 1999; Ravn and Sola, 2004; Kandil, 2006; among many others), the size (Weise, 1999; Ravn and Sola, 2004; Lo and Piger, 2005; Mitchell and Robinson, 2009), and the persistence (Japelli and Pistaferri, 2010) of the policy intervention. Theoretical rationales put forward to explain these macroeconomic asymmetries range from real phenomena such as, e.g., capacity constraints (Hansen and Prescott, 2005), labor adjustment costs (Kohlbacher and Merkl, 2016), adjustment costs for household consumption (Hussain and Malik, 2016), or borrowing and collateral constraints (Balleer et al., 2015; Cloyne et al., 2016; Guerrieri and Iacoviello, 2015) to nominal phenomena such as downward nominal wage rigidity (Abritti and Fahr, 2013) and (asymmetric) price rigidity (Ball and Mankiw, 1994; Balleer et al., 2015). This paper offers an additional theoretical rationale for explaining business cycle asymmetries based on nominal price rigidity.

While the papers above mostly study the asymmetric response of output directly, our paper focuses on asymmetries in firm pricing. And although our paper is a partial-equilibrium, microeconomic analysis, our results have some potentially important, suggestive macroeconomic implications for asymmetric responses of output mentioned above. Therefore, this paper contributes to the macroeconomic literature on asymmetric responses to economic shocks as well as to the microeconomic literature on firm pricing.

We now consider the empirical evidence suggesting state-dependent pricing in the form that prices respond imperfectly and asymmetrically to exogenous positive and negative demand shocks of equal magnitude, that the implied asymmetry depends on whether the shock is permanent or temporary, that the degree of asymmetry depends on whether the shock is small or large.

The importance of state-dependence for firms' pricing decisions is well documented. For instance, in the countries of the euro area (Fabiani et al., 2006; Nicolitsas, 2013), Scandinavia (Apel et al., 2005; Langbraaten et al., 2008; Ólafsson et al., 2011), the United States (Blinder et al., 1998), and Turkey (Şahinöz and Saraçoğlu, 2008), approximately two third of the firms' pricing decisions are indeed driven by the current state of the environment. Only in the United Kingdom (Hall et al., 2000) and Canada (Amirault et al., 2004) state-dependence seems to be somewhat less important for firms' pricing decision.

There is much empirical evidence for the proposition that, with regard to permanent demand shocks, prices are generally more responsive to positive shocks than to negative ones. For example, in the context of monetary policy shocks, Kandil (1995, 1996, 2002b) and Weise (1999) find support for the United States over a large range of different samples. Moreover, Kandil (1995) and Karras and Stokes (1999) supply evidence for large panels of industrialized OECD countries, while Karras (1996) provides evidence for developing countries. In the case of the United States, Kandil (2001, 2002a) shows that the asymmetry also prevails in response to permanent government spending shocks. Kandil (1999, 2006, 2010), on the other hand, looks directly at permanent aggregate demand shocks and also confirms the asymmetry for a large set of industrialized countries as well as for a sample of disaggregated industries in the United

States. Comparing a large set of industrialized and developing countries, Kandil (1998) finds that the asymmetry is even stronger for many developing countries compared to industrialized ones.

There is also significant empirical evidence for the proposition that, with regard to temporary demand shocks, prices are generally less responsive to positive shocks than to negative ones. For example, the survey by Hall et al. (2000) indicates that firms regard price increases as response to temporary increases in demand to be among the least favorable options. Instead, firms rather employ more workers, extend overtime work, or increase capacities. By contrast, managers of firms state that a temporary fall in demand is much more likely to lead to a price cut. Further evidence for the asymmetry in response to temporary demand shocks is provided by Kehoe and Midrigan (2008), who analyze temporary price movements at Dominick's Finer Foods retail chain with weekly store-level data from 86 stores in the Chicago area. They find that temporary price reductions are much more frequent than temporary price increases and that, on average, temporary price cuts are larger (by a factor of almost two) than temporary price increases.

There is also evidence that prices are more likely to respond to large demand shocks rather than to small demand shocks and that the responses are asymmetric especially for large shocks but not so much for small shocks. Surveying 873 Austrian firms, Kwapil et al. (2010) find that prices are equally likely to remain unchanged in response to a small positive demand shock, as they are in response to a small negative shock. In response to large demand shocks, however, firms are not only generally more likely to change their price compared to small shocks, but also respond significantly asymmetric to positive and negative shocks. Comparable empirical support is provided by Weise (1999) for the United States. Weise (1999) finds that large monetary policy shocks have strong and asymmetric price effects, whereas small monetary policy shocks have comparably little and rather symmetric price effects.

Despite this broad evidence, asymmetric reactions to demand shocks along these three dimensions have been unexplored by current theories of price adjustment. Neither time-dependent pricing models (Taylor, 1979; Calvo, 1983), state-dependent adjustment cost models of (S, s) type (e.g., Sheshinski and Weiss, 1977; Rotemberg, 1982; Caplin and Spulber, 1987; Caballero and Engel, 1993, 2007; Golosov and Lucas, 2007; Gertler and Leahy, 2008; Dotsey et al., 2009; Midrigan, 2011) nor hybrids of price- and state-dependent models (e.g., Ball and Mankiw, 1994; Devereux and Siu, 2007) are able to account for the asymmetry properties in price dynamics in response to small and large positive and negative exogenous temporary and permanent shifts in demand. The theory of state-dependent price adjustment based on consumer loss aversion proposed in this paper, by contrast, is consonant with the empirical evidence on price setting outlined above.

The key to our approach in accounting for these empirical regularities lies in the interaction between the kinked demand curve and the dynamics of the reference-price updating process. While there are rationales other than loss aversion for non-linear demand curves such as liquidity and credit constraints (Cloyne et al., 2016) or consumption adjustment costs (see Japelli and Pistaferri (2010) for a survey), these rationales are associated with price dynamics that differ from those implied by the reference-price dependence in this paper. Hussain and Malik (2016), for instance, analyze consumption

demand decisions under asymmetric consumption adjustment costs with consumption habits. Though their approach allows them to account for firms' asymmetric price responses to large positive and negative demand shocks, they do not explain the asymmetry of price responses to temporary and permanent demand shocks.

There are of course few other papers that study the implications of consumer loss aversion on firms' pricing decisions. An early account of price rigidity in response to demand and cost shocks has been presented by Sibly (2002, 2007). In a static environment, Sibly (2002, 2007) shows that a monopolist may not change prices if she faces loss averse consumers with fixed, exogenously given reference prices. In their particularly insightful contributions, Heidhues and Köszegi (2008) and Spiegel (2012) analyze static monopolistic pricing decisions to cost and demand shocks under the assumption that the reference price is determined as a consumer's recent rational expectations personal equilibrium in the spirit of Köszegi and Rabin (2006) and confirm earlier findings. Furthermore, Spiegel (2012) shows that incentives for price rigidity are even stronger for demand shocks compared to cost shocks. While these contributions can explain why loss aversion leads to asymmetric price responses, due to their static nature, they cannot differentiate between temporary and permanent shocks. This paper, by contrast, considers a dynamic approach to the pricing decision of a monopolistically competitive firm facing loss averse consumers with endogenous, rational expectations-driven reference price formation. Our dynamic approach confirms earlier findings that consumer loss aversion engenders price rigidity. Furthermore, our approach yields the advantage that it allows us to study the asymmetry characteristics of pricing reactions to temporary and permanent demand shocks of different size and sign. Another study with a dynamic approach is Popescu and Wu (2007), who model loss averse consumers with endogenous reference prices that are determined by an exponentially smoothed average of past prices. Although they analyze optimal pricing strategies in repeated market interactions, they do not analyze the model's reaction to demand or cost shocks. As we will argue, it is the interaction between the dynamic model of loss aversion and rational expectations-driven reference price formation, which allows us to explain the full spectrum of empirical evidence outlined above.

Although there is no hard evidence for a direct link from consumer loss aversion to price sluggishness, to the best of our knowledge, there is ample evidence that firms do not adjust their prices flexibly in order to avoid harming their customer relationships (see, e.g., Fabiani et al. (2006) for a survey of euro area countries, Blinder et al. (1998) for the United States², and Hall et al. (2000) for the United Kingdom).³

Furthermore, there is extensive empirical evidence that customers are indeed loss

²In their survey, Blinder et al. (1998) additionally find clear evidence that the pricing of those firms for which the fear of antagonizing their customers through price changes plays an important role is relatively upward sluggish. Unfortunately, the authors do not distinguish between temporary and permanent shifts in demand in their survey questions.

³Further evidence for OECD countries is provided by, for example, Fabiani et al. (2004) for Italy, Loupias and Ricart (2004) for France, Zbaracki et al. (2004) for the United States, Alvarez and Hernando (2005) for Spain, Amirault et al. (2005) for Canada, Aucremanne and Druant (2005) for Belgium, Stahl (2005) for Germany, Lünemann and Mathä (2006) for Luxembourg, Langbraaten et al. (2008) for Norway, Hoeberichts and Stokman (2010) for the Netherlands, Kwapił et al. (2010) for Austria, Martins (2010) for Portugal, Ólafsson et al. (2011) for Iceland, and Greenslade and Parker (2012) for the United Kingdom.

averse in prices. Kalwani et al. (1990), Mayhew and Winer (1992), Krishnamurthi et al. (1992), Putler (1992), Hardie et al. (1993), Kalyanaram and Little (1994), Raman and Bass (2002), Dossche et al. (2010), and many others find evidence for consumer loss aversion with respect to many different product categories available in supermarkets. Loss aversion in prices is also well documented in diverse activities such as restaurant visits (Morgan, 2008), vacation trips (Nicolau, 2008), real estate trade (Genesove and Mayer, 2001), phone calls (Bidwell et al., 1995), and energy use (Griffin and Schulman, 2005; Adeyemi and Hunt, 2007; Ryan and Plourde, 2007).

In our model, loss-averse consumers evaluate prices relative to a reference price. Kőszegi and Rabin (2006, 2007, 2009) and Heidhues and Kőszegi (2005, 2008, 2014) argue that reference points are determined by agents' rational expectations about outcomes from the recent past. There is much empirical evidence suggesting that reference points are determined by expectations, in concrete situations such as in police performance after final offer arbitration (Mas, 2006), in the United States TV show "Deal or no Deal" (Post et al., 2008), with respect to domestic violence (Card and Dahl, 2011), in cab drivers' labor supply decisions (Crawford and Meng, 2011), in the effort choices of professional golf players (Pope and Schweitzer, 2011), or in the aggressiveness of professional soccer players (Bartling et al., 2015). In the context of laboratory experiments, Knetsch and Wong (2009) and Marzilli Ericson and Fuster (2011) find supporting evidence from exchange experiments, Abeler et al. (2011) and Gill and Prowse (2012) from effort provision experiments, Banerji and Gupta (2014) from an auction experiment, and Karle et al. (2015) from a consumption choice experiment. Endogenizing consumers' reference prices in this way allows our model to capture that current price changes influence the consumers' future reference price and thereby affect the demand functions via what we call the "reference-price updating effect." This effect rests on the observation that firms tend to increase the demand for their product by raising their consumers' reference price through, for example, setting a "suggested retail price" that is higher than the price actually charged (Thaler, 1985; Putler, 1992). These pieces of evidence are consonant with the assumptions underlying our analysis. Our analysis works out the implications of these assumptions for state-dependent price sluggishness in the form of asymmetric price adjustment for temporary and permanent demand shocks.

3. Model

We incorporate reference-dependent preferences and loss aversion into an otherwise standard model of monopolistic competition. Consumers are price takers and loss averse with respect to prices. They evaluate prices relative to their reference prices, which depend on their lagged rational price expectations from the recent past, i.e. consumers are backward-looking. For simplicity, we abstract from saving, implying that workers become single-period optimizers. Firms are monopolistic competitors, supplying non-durable differentiated goods. Firms can change their prices freely in each period to maximize their total expected discounted profits. Firms' price setting decision is forward-looking, taking into account their influence on the consumers' future reference price. Thus, reference dependence in our model is obviously an intertemporal phenomenon, linking the decisions in one period to the decisions in the next. To analyse

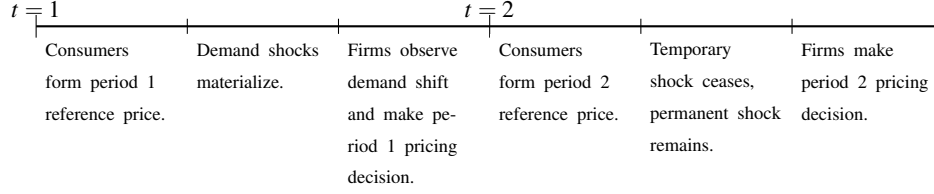


Figure 1: Sequence of events in the two-period model

the firms' price setting decision in response to demand shocks in such an intertemporal context, we consider a dynamic two-period analysis, for algebraic simplicity.⁴

The sequence of events is as follows: At the beginning of the first period, consumers form their reference price which equals the steady state price. Afterwards, a deterministic demand shock materializes unexpectedly. Firms observe the shift in demand and decide whether and by how much to change their current-period price while taking into account the consumers' reference price reaction in the next period. At the beginning of the second period, consumers can infer whether the demand shock and the corresponding, observed price change are of temporary or permanent nature and update their price expectations accordingly. This may or may not result in an adjustment of their second-period reference price. Afterwards, depending on the nature of the shock, the deterministic demand shock ceases or remains. Firms decide whether to keep or change back their second-period price. Figure 1 summarizes the sequence of events visually.

3.1. Consumers

We follow Sibly (2007) and assume that the representative consumer's period-utility U_t depends positively on the consumption of n imperfectly substitutable non-durable goods $q_{i,t}$ with $i \in (1, \dots, n)$ and negatively on the "loss-aversion ratio" $(P_{i,t}/R_{i,t})$, i.e. the ratio of the price $P_{i,t}$ of good i to the consumer's respective reference price $R_{i,t}$ of the good.⁵ The loss-aversion ratio, which describes how the phenomenon of loss aversion enters the utility function, may be rationalized in terms of Thaler's transaction utility (whereby the total utility that the consumer derives from a good is in part determined by how the consumer evaluates the quality of the financial terms of the acquisition of the good (Thaler, 1991, 2008)). Experimental support for this assumption comes from Grewal et al. (1998) and Muehlbacher et al. (2011). Grewal et al. (1998) find that transaction utility has an influence on acquisition utility. Further approaches that describe reference dependence in the consumer's utility function in terms of a ratio of actual prices to reference prices are McDonald and Sibly (2001, 2005) and Ahrens et al. (2015) in the context of loss aversion with respect to wages and Sibly

⁴A multi-period analysis with longer time horizons would not affect our qualitative conclusions.

⁵Throughout the model, capital letters denote nominal variables, while small letters denote real variables. Greek letters denote model parameters.

(2002, 2007) in the context of loss aversion with respect to prices.⁶ The consumer's preferences in period t are represented by the following utility function:⁷

$$U_t(q_{1,t}, \dots, q_{n,t}) = \left[\sum_{i=1}^n \left(\left(\frac{P_{i,t}}{R_{i,t}} \right)^{-\mu} q_{i,t} \right)^\rho \right]^{\frac{1}{\rho}}, \quad (1)$$

where $0 < \rho < 1$ denotes the degree of substitutability between the different goods. The parameter μ is an indicator function of the form

$$\mu = \begin{cases} \Gamma & \text{for } P_{i,t} < R_{i,t}, \text{ i.e. gain domain} \\ \Delta & \text{for } P_{i,t} > R_{i,t}, \text{ i.e. loss domain} \end{cases}, \quad (2)$$

which describes the degree of the consumer's loss aversion. For loss averse consumers, $\Delta > \Gamma$, i.e. the utility losses from price increases are larger than the utility gains from price decreases of equal magnitude. The consumer's reference price $R_{i,t}$ is formed at the beginning of each period. In the spirit of Köszegi and Rabin (2006), we assume that the consumer's reference price depends on her lagged rational price expectation, i.e. $R_{i,t} = E[P_{i,t} | I_{t-1}]$. Demand shocks, which may or may not trigger price adjustment, materialize unexpectedly in the course of the period and therefore do not enter the information set used by the consumer at the beginning of the period to form the reference price. Therefore, there is no instantaneous reaction of the reference price in the shock period even if the firm immediately adjusts its price in response to the shock. At the beginning of the next period, however, consumers adjust their recent price expectation according to their updated information set. Specifically, they can infer whether the demand shock and the corresponding price change are of temporary or permanent nature. Temporary price changes do not provoke a change in the consumer's reference price because consumers expect the price to be reset to the pre-shock level.⁸ By contrast, the reference price changes in the period after the occurrence of a permanent (i.e. fully persistent) shock as consumers expect the adjusted price to persist in period 2. Formally, this means that

$$\Delta R_{i,t} = R_{i,t} - R_{i,t-1} \begin{cases} = 0 & \text{if } E[P_{i,t} | I_{t-1}] \neq P_{i,t-1}, \text{ i.e. temporary shocks} \\ \neq 0 & \text{if } E[P_{i,t} | I_{t-1}] = P_{i,t-1}, \text{ i.e. permanent shocks.} \end{cases} \quad (3)$$

⁶Other examples in which prices directly enter the utility function are, for instance, Rosenkranz (2003) and Rosenkranz and Schmitz (2007) in the context of auctions and Popescu and Wu (2007), Nasiry and Popescu (2011), and Zhou (2011) in the context of customer loss aversion.

⁷Tversky and Kahneman (1991) find that iso-elastic functions of CES type are consistent with their experimental evidence on loss aversion.

⁸Support for this assumption can be found in the example of sales, i.e. promotions, characterized by non-permanent price decreases, used by firms to temporarily increase consumers' demand for their product (see, e.g., Eichenbaum et al., 2011). One-time price promotions do not affect the consumers' reference price (Kalwani and Yim, 1992; Sinha and Smith, 2000; DelVecchio et al., 2007; Lowe et al., 2014). Otherwise firms would not conduct sales because any downward adjustment of the consumer's reference price reduces long-run profits for the firm.

The consumer's budget constraint is given by

$$\sum_{i=1}^n P_{i,t} q_{i,t} = \tilde{P}_t y_t \varepsilon_t, \quad (4)$$

where y_t denotes the consumer's real income in period t which is assumed to be constant, \tilde{P}_t is the aggregate price index, and $\varepsilon_t = \varepsilon_{t-1}^{\rho_\varepsilon} e^{u_t}$ is an aggregate demand shock with persistence ρ_ε and deterministic innovation u_t . Demand shocks may be temporary (i.e. $\rho_\varepsilon = 0$) or permanent (i.e. $\rho_\varepsilon = 1$). Both the temporary and permanent shocks occur at the macro level and can be interpreted as changes in nominal income arising from exogenous change in macro policy. For simplicity, we abstract from saving. This implies that consumers are completely myopic.⁹ In each period the consumer maximizes her period-utility function (1) with respect to her budget constraint (4). The result is the consumer's period t demand for the differentiated good i which is given by

$$q_{i,t}(P_{i,t}, R_{i,t}, \mu) = \tilde{P}_t^\eta \left(\frac{P_{i,t}}{R_{i,t}} \right)^{-\mu(\eta-1)} \frac{y_t \varepsilon_t}{P_{i,t}^\eta}, \quad (5)$$

where $\eta = \frac{1}{1-\rho}$ denotes the elasticity of substitution between the different product varieties. The aggregate price index \tilde{P}_t is given by

$$\tilde{P}_t = \left[\sum_{i=1}^n \left(P_{i,t} / \left(\frac{P_{i,t}}{R_{i,t}} \right)^{-\mu} \right)^{1-\eta} \right]^{\frac{1}{1-\eta}}. \quad (6)$$

We assume that the number of firms n is sufficiently large so that the pricing decision of a single firm does not affect the aggregate price index. Defining $\lambda = \eta(1+\mu) - \mu$, we can simplify equation (5) to

$$q_{i,t}(P_{i,t}, R_{i,t}, \lambda) = R_{i,t}^{\lambda-\eta} P_{i,t}^{-\lambda} \tilde{P}_t^\eta y_t \varepsilon_t, \quad (7)$$

where the parameter λ denotes the price elasticity of demand, which depends on μ and therefore takes different values for losses and gains. To simplify notation, we denote the (absolute) demand elasticity by

$$\lambda = \begin{cases} \gamma & \text{for } P_{i,t} < R_{i,t} \\ \delta & \text{for } P_{i,t} > R_{i,t} \end{cases}, \quad (8)$$

with $\delta = \eta(1+\Delta) - \Delta > \gamma = \eta(1+\Gamma) - \Gamma$. Equation (7) indicates that the consumer's demand function for good i is kinked at the reference price $R_{i,t}$. The kink, lying at the intersection of the two demand curves $q_{i,t}(P_{i,t}, R_{i,t}, \gamma)$ and $q_{i,t}(P_{i,t}, R_{i,t}, \delta)$, is given by

⁹Evidence to support this assumption is provided by Elmaghraby and Keskinocak (2003) who show that many purchase decisions of non-durable goods take place in economic environments which are characterized by myopic consumers.

the price-quantity combination

$$(\widehat{P}_{i,t}, \widehat{q}_{i,t}) = (R_{i,t}, R_{i,t}^{-\eta} \bar{P}_t^\eta y_t \varepsilon_t), \quad (9)$$

where “ $\widehat{\cdot}$ ” denotes the value of a variable at the kink. Changes in the reference price $R_{i,t}$ give rise to a change of the position of the kink and also shift the demand curve as a whole. The direction of this shift depends on the sign of the difference $\lambda - \eta$. We restrict our analysis to $\lambda \geq \eta$, i.e. we assume that an increase in the reference price shifts the demand curve outwards and vice versa.¹⁰

Needless to say, abstracting from reference dependence and loss aversion in the consumer’s preferences represented by utility function (1), restores the standard textbook consumer demand function for a differentiated good i , given by

$$q_{i,t}(P_{i,t}) = P_{i,t}^{-\eta} \bar{P}_t^\eta y_t \varepsilon_t, \quad (10)$$

where \bar{P}_t is the aggregate price index in an economy without loss averse consumers.

3.2. Monopolistic Firms

Firms seek to maximize the discounted stream of current and future profits,

$$\Pi_{i,t}^{Total} = \Pi_{i,t} + \beta \Pi_{i,t+1} \quad (11)$$

where $\Pi_{i,t} = P_{i,t} q_{i,t} - C(q_{i,t})$ are period t profits, β is the discount factor and $C_t(q_t)$ are firm’s total costs. For simplicity, we assume a firm lives only for two periods. The firm takes into account its period t individual downward-sloping demand function (7) and the implications of its current pricing decision for the costumers’ reference price. The resulting first order condition of the firm’s optimization problem reads as

$$\frac{\partial \Pi_{i,t}^{Total}}{\partial P_{i,t}} = q_{i,t} + P_{i,t} \frac{\partial q_{i,t}}{\partial P_{i,t}} - \frac{\partial C(q_{i,t})}{\partial q_{i,t}} \frac{\partial q_{i,t}}{\partial P_{i,t}} + \beta \frac{\partial \Pi_{i,t+1}}{\partial R_{i,t+1}} \frac{\partial R_{i,t+1}}{\partial P_{i,t}} = 0, \quad (12)$$

which is equivalent to

$$\underbrace{q_{i,t} \frac{\partial P_{i,t}}{\partial q_{i,t}} + P_{i,t}}_{MR_t} - \underbrace{\frac{\partial C(q_{i,t})}{\partial q_{i,t}}}_{MC_t} = -\beta \frac{\partial \Pi_{i,t+1}}{\partial R_{i,t+1}} \frac{\partial R_{i,t+1}}{\partial P_{i,t}} \frac{\partial P_{i,t}}{\partial q_{i,t}}. \quad (13)$$

The term on the left hand side is the current-period marginal revenue MR_t minus the current-period marginal cost MC_t . The term on the right hand side measures the influence of the price setting decision on the reference price and thereby future profits, i.e.

¹⁰The positive relationship between reference price and demand has become a common feature in the marketing sciences (e.g., Thaler, 1985; Putler, 1992; Greenleaf, 1995). It manifests itself, e.g., through the “suggested retail price,” by which raising the consumers’ reference price causes increases in demand (Thaler, 1985). Furthermore, Putler (1992) provides evidence that an extensive use of promotional pricing in the late 80’s had lead to an erosion in demand by lowering consumers’ reference prices.

the marginal gain of the reference-price updating effect. In the absence of reference-price updating the standard optimality condition of a firm holds, i.e. $MR_t = MC_t$. Only if the firm's price setting decision has an influence on the reference price the firm faces a tradeoff between current period optimality (determined by the left hand side of equation (13)) and future ramifications of the current decision (determined by the right hand side of equation (13)).

All n firms are identical, enabling us to drop the subscript i . In what follows we assume that the firm's total costs are given by $C_t(q_t) = \frac{c}{2}q_t^2$, where c is a constant, implying that marginal costs are linear in output: $MC_t(q_t) = cq_t$. In the presence of loss aversion ($\delta > \gamma$), the downward-sloping demand curve has a concave kink at the current reference price: $\bar{P}_t = R_t$. Thus the firm's marginal revenue curve is discontinuous at the kink:

$$MR_t(q_t, R_t, \lambda) = \left(1 - \frac{1}{\lambda}\right) \left(\frac{q_t}{R_t^{(\lambda-\eta)} \bar{P}_t^\eta y_t \varepsilon_t}\right)^{-\frac{1}{\lambda}}, \quad (14)$$

with $\lambda = \gamma$ for the gain domain and $\lambda = \delta$ for the loss domain, respectively. The interval $[MR_t(\hat{q}_t, R_t, \gamma), MR_t(\hat{q}_t, R_t, \delta)]$, where $MR_t(\hat{q}_t, R_t, \gamma) < MR_t(\hat{q}_t, R_t, \delta)$, we call "marginal revenue discontinuity" $MRD_t(\hat{q}_t, R_t, \gamma, \delta)$.

We assume that in the initial steady state, the exogenously given reference price is R_{ss} . Furthermore, in the steady state the firm's marginal cost curve intersects the marginal revenue discontinuity, as depicted in Figure 2. The assumption implies that the firm's optimal price in the initial steady state P_{ss}^* is equal to R_{ss} .¹¹ To fix ideas, we first assume that initially the marginal cost curve crosses the midpoint of the discontinuity in the marginal revenue curve.¹² This assumption permits us to derive the symmetry characteristics of the price responses to positive and negative demand shocks of equal magnitude. We relax on this assumption and discuss how the results change.

3.3. Demand Shocks

We consider the effects of a demand shock that hits the economy in period t . The demand shock shifts the marginal revenue curve, along with the marginal revenue discontinuity $MRD_t(\hat{q}_t, R_t, \gamma, \delta, \varepsilon_t)$. We define a "small" shock as one that leaves the marginal cost curve passing through the marginal revenue discontinuity, and a "large" shock as one that shifts the marginal revenue curve sufficiently so that the marginal cost curve no longer passes through the marginal revenue discontinuity.

The maximum size of a small shock for the demand function (7) is

$$\bar{\varepsilon}_t(\lambda) = \left(1 - \frac{1}{\lambda}\right) \frac{R_t^{1+\eta}}{c \bar{P}_t^\eta y_t}, \quad (15)$$

¹¹The proof is straightforward: Let v be an arbitrarily small number. Then for prices equal to $R_{ss} + v$ the firm faces a situation in which marginal revenue is higher than marginal costs and decreasing the price would raise the firm's profit, while for prices equal to $R_{ss} - v$ the firm faces a situation in which marginal revenue is lower than marginal costs and increasing the price would raise the firm's profit. Thus $P_{ss}^* = R_{ss}$ has to be the profit maximizing price in the initial steady state.

¹²To satisfy this condition, the slope parameter c of the marginal cost curve has to take the value $c_{mid} = \frac{1}{2q_{ss}} [MR_t(q_{ss}, R_{ss}, \gamma) + MR_t(q_{ss}, R_{ss}, \delta)]$.

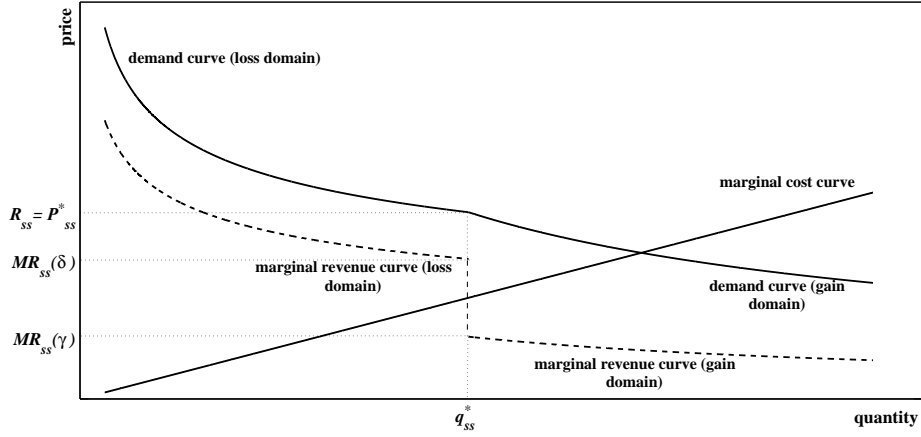


Figure 2: Initial steady state

i.e. $\bar{\epsilon}_t(\lambda)$ is the shock size for which the marginal cost curve lies exactly on the boundaries of the shifted marginal revenue discontinuity $MRD_t(\hat{q}_t, R_t, \gamma, \delta, \bar{\epsilon}_t(\lambda))$.¹³

Note that under the assumption that the marginal cost curve crosses the midpoint of the marginal revenue discontinuity, the critical shock size given by (15) is symmetric for positive and negative demand shocks. This is not the case, however, if the marginal cost curve crosses the marginal revenue discontinuity above or below its midpoint. For an intersection closer to the upper bound of the marginal revenue discontinuity, the critical shock size decreases for a positive shock and increases for a negative shock. In the limit case, when the intersection is exactly onto the upper bound, the critical shock size reduces to zero for the positive shocks and becomes maximal for the negative shocks. Analogously, the opposite holds true when the intersection moves closer to the lower bound of the marginal revenue discontinuity. Therefore, the location of the intersection of the marginal cost curve with the marginal revenue discontinuity, obviously, has implications for the asymmetry characteristics of price responses to equiproportionate negative and positive demand shocks. We discuss these implications in detail in Section 4.

In the analysis that follows, we distinguish both between small and large positive and negative demand shocks and between temporary and permanent positive and negative demand shocks. To qualitatively and quantitatively assess the price setting reaction of the firm we calibrate the model and simulate it numerically.

3.4. Calibration

We calibrate the model for a quarterly frequency in accordance with standard values in the literature. We assume an annual interest rate of 4 percent, which yields a discount factor $\beta = 0.99$. We follow Schmitt-Grohé and Uribe (2007) and set the

¹³For $\bar{\epsilon}(\delta)$, the marginal cost curve intersects the marginal revenue gap on the upper bound, whereas for $\bar{\epsilon}(\gamma)$ it intersects it on the lower bound.

Parameter	Symbol	Value
Discount rate	β	0.99
Elasticity of substitution	η	5
implying substitutability	ρ	0.8
Price elasticity (gain domain)	γ	5.5
Price elasticity (loss domain)	δ	11
Loss aversion	κ	2
Exogenous nominal income	Y	1
Exogenous price index	\bar{P}_t	1
Persistence of demand shock	ρ_ε	$\in \{0, 1\}$

Table 1: Base calibration

monopolistic markup to 25 percent, i.e. $\eta = 5$, which is also close to the value supported by Erceg et al. (2000) and which implies that goods are only little substitutable, i.e. $\rho = 0.8$. Loss aversion is measured by the relative slopes of the demand curves in the gain and loss domain, i.e. $\kappa = \frac{\delta}{\gamma}$. The empirical literature on loss aversion in prices finds that losses induce demand reactions approximately twice as large as gains (Tversky and Kahneman, 1991; Putler, 1992; Kalyanaram and Little (1994); Griffin and Schulman, 2005; Adeyemi and Hunt, 2007). Therefore, we set $\kappa = 2$. The loss aversion parameters from the utility function Γ and Δ are chosen to match specific price elasticities. Price elasticities are commonly values as low as 5 (e.g., Klenow and Willis, 2006) up to values as high as 11 (e.g., Kimball, 1995; Chari et al., 2000; Eichenbaum and Fisher, 2004; Woodford, 2005). Therefore, we set the price elasticity in the gain domain to $\gamma = 5.5$, which given $\kappa = 2$ implies a price elasticity in the loss domain of $\delta = 11$. Furthermore, this calibration satisfies the restriction that $\lambda \geq \eta$. The exogenous nominal income Y and price index P_t are normalized to unity.¹⁴ For temporary shocks, we calibrate $\rho_\varepsilon = 0$, i.e. they have zero persistence. For permanent shocks we calibrate $\rho_\varepsilon = 1$, i.e. they have full persistence. The deterministic innovations $u_1 \neq 0$ are chosen so match equiproportionate variations for positive and negative ε_t . The base calibration is summarized in Table 1.

4. Results

Figure 3 present the numerical results of our base calibration in the two-period model. In the figure we show the shock-arc-elasticity of price ($\tilde{\eta}_{\varepsilon, P} = \frac{\% \Delta P}{\% \Delta \varepsilon}$) in the period of the shock t for positive and negative temporary (left panel) and permanent (right panel) demand shocks. On the vertical axis we show the shock-arc elasticities of price, which measure the relative strength of the price reaction in response to demand shocks. The horizontal axis measures the size of the shock in percent. The gray vertical lines in both panels depict the symmetric critical shock size given by equation (15) which divides the plane into small (to the left of the line) and large (to the right of the

¹⁴All results are completely robust to variations of these numerical values.

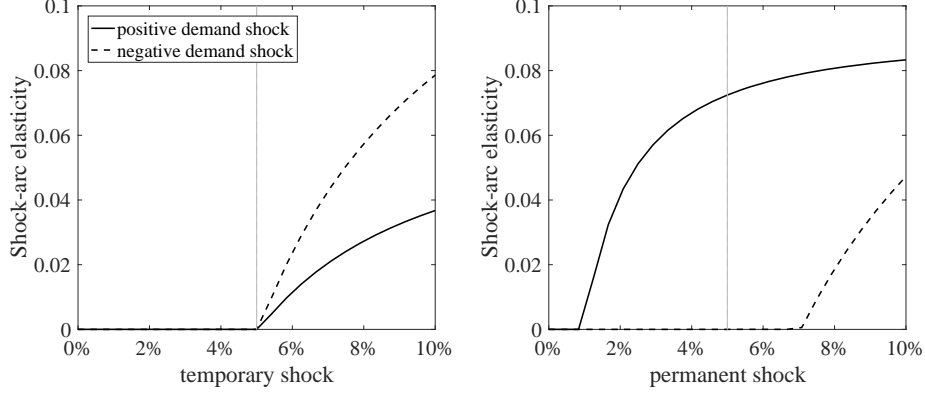


Figure 3: Shock-arc elasticities to temporary and permanent demand shocks

line) demand shocks.

Our numerical analysis finds that the firm's price reaction in response to demand shocks depends crucially on the size, the sign, and the persistence (temporary vs. permanent) of the shock. The left panel of Figure 3 shows that prices are completely rigid for small positive and negative temporary demand shocks (to the left of the gray vertical line), while they are relatively upward sluggish for large shocks (to the right of the gray vertical line). By contrast, the right panel of Figure 3 shows that in response to permanent positive demand shocks prices are generally downward sluggish. The range of full price rigidity is small, as even many small positive permanent demand shocks induce a positive price reaction. By contrast, in response to permanent negative demand shocks, prices remain fully rigid also for a considerable range of large shocks. In the following we will analyse the intuition for these results.

4.1. Intuition

Temporary demand shocks

Consider first a temporary shock. For a temporary (one-period) demand shock, the consumers' reference price is not affected (since information reaches them with a one-period lag and they have rational expectations). This implies that $\frac{\partial R_{t+1}}{\partial P_t} = 0$ and thus the firm's price response to the shock is the same as that of a myopic firm (which maximizes its current period profit). According to the optimality condition (13), the new profit-maximizing price is determined by the standard condition according to which $MR_t = MC_t$.

Result 1: *In response to a small temporary shock, prices remain rigid.*

As noted, for a sufficiently small demand shock $\epsilon_t^s \leq \bar{\epsilon}_t(\lambda)$ the marginal cost curve still intersects the marginal revenue discontinuity, i.e. $MC_t(\hat{q}_t) \in MRD_t(\hat{q}_t, R_{ss}, \gamma, \delta, \epsilon_t^s)$.

Therefore, the prevailing steady state price remains the firm's profit-maximizing price,¹⁵ i.e. $P_t^* = P_{ss}^*$, and we have complete price rigidity. By contrast, the profit-maximizing quantity changes to $q_t^* = R_{ss}^{-\eta} \bar{P}_t^\eta y_t \varepsilon_t^s$, thus the percentage change of quantity is given by

$$\Delta q_t^* = \frac{q_t^* - q_{ss}^*}{q_{ss}^*} = \frac{\varepsilon_t^s - 1}{1} = \varepsilon_t^s - 1 \neq 0. \quad (16)$$

This holds true irrespective of the sign of the small temporary demand shock. Consequently, the quantity reaction is symmetric for positive and negative small demand shocks of equal magnitude.

Result 2: *In response to a large temporary shock, prices are more sluggish upwards than downwards.*

For a large shock, i.e. $\varepsilon_t^l > \bar{\varepsilon}_t(\lambda)$, the marginal cost curve intersects the marginal revenue curve outside the discontinuity of the latter. Consequently both, a price and a quantity reaction are induced. The new profit-maximizing price of the firm is

$$P_t^* = \left(\frac{R_{ss}^{(\lambda-\eta)} \bar{P}_t^\eta y_t \varepsilon_t^l}{q_t^*} \right)^{\frac{1}{\lambda}}, \quad (17)$$

while its corresponding profit-maximizing quantity is

$$q_t^* = \left(\frac{1}{c} \left(1 - \frac{1}{\lambda} \right) \right)^{\frac{\lambda}{\lambda+1}} \left(R_{ss}^{(\lambda-\eta)} \bar{P}_t^\eta y_t \varepsilon_t^l \right)^{\frac{1}{\lambda+1}}, \quad (18)$$

where $\lambda = \delta$ for positive and $\lambda = \gamma$ for negative shocks, respectively.

In comparison to the standard firm the price reaction of the firm facing loss-averse consumers in response to a large temporary demand shock is always smaller, whereas the quantity reaction is always larger. Additionally, prices and quantities are less responsive to positive than to negative shocks. The intuition is obvious once we decompose the demand shock into the maximum small shock and the remainder:

$$\varepsilon_t^l = \bar{\varepsilon}_t(\lambda) + \varepsilon_t^{rem}. \quad (19)$$

From our theoretical analysis above, the maximum small shock $\bar{\varepsilon}_t(\lambda)$ has no price effects, but feeds one-to-one into demand. This holds true irrespective of the sign of the shock. By contrast, the remaining shock ε_t^{rem} has asymmetric effects. Let \bar{q}_t be the quantity corresponding to $\bar{\varepsilon}_t(\lambda)$. Then the percentage change in quantity in response to ε_t^{rem} is given by

$$\Delta q_t^{rem} = \frac{q_t^* - \bar{q}_t}{\bar{q}_t} = \left(1 + \frac{\varepsilon_t^{rem}}{\bar{\varepsilon}_t(\lambda)} \right)^{\frac{1}{\lambda+1}} - 1. \quad (20)$$

¹⁵Compare the proof from Section 3.2.

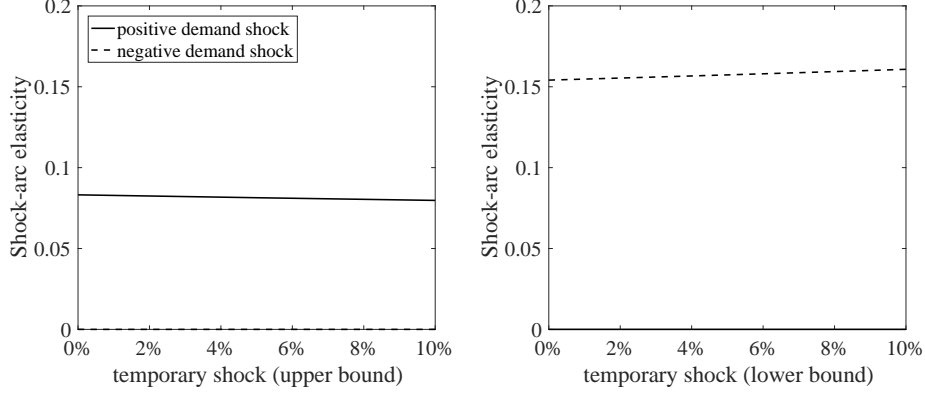


Figure 4: Shock-arc elasticities to positive and negative demand shocks if the marginal cost curve crosses the upper (left panel) and lower (right panel) bound of the marginal revenue gap

As can be seen from equation (20), the change of quantity in response to ε_t^{rem} depends negatively on λ , the price elasticity of demand. Since by definition $\delta > \gamma$, the quantity reaction of the firm facing loss-averse consumers is smaller in response to large positive temporary demand shocks than to large negative ones. This however implies that prices are also less responsive to positive than to negative large temporary demand shocks, because the former move the firm along the relatively flat portion of the demand curve, whereas the latter move it along the relatively steep portion of the demand curve. This asymmetric sluggishness in the reaction to positive and negative large temporary demand shocks is a distinct feature of consumer loss aversion and stands in obvious contrast to the standard textbook case of monopoly pricing.

While ε_t^{rem} is equal for large positive and negative shocks of equal size under the assumption that the marginal cost curve crosses the midpoint of the marginal cost discontinuity, ε_t^{rem} increases (decreases) for large positive shocks and decreases (increases) for large negative shocks, if the marginal cost curve intersects closer to the upper (lower) bound of the marginal revenue discontinuity. Figure 4 shows the shock-arc-elasticity of price in the shock-period t for temporary positive and negative demand shocks, when the marginal cost curve crosses the marginal revenue gap exactly on the upper bound (left panel) and exactly on the lower bound (right panel). While a lower intersection amplifies the upward sluggishness of prices, a higher intersection dampens the upward sluggishness of prices and eventually reverses it. To see this intuitively, consider the limit case when the intersection is exactly on the upper bound. Now, $\bar{\varepsilon}(\delta) = 0$ and thereby any positive shock has a price effect, whereas $\bar{\varepsilon}(\gamma) = \max$ and thereby the range of price rigidity in response to negative shocks becomes maximal. Hence, in this case, we have downward price rigidity.

Permanent demand shocks

Now consider a permanent demand shock that occurs in period t . For a permanent (two-period) demand shock, the consumers' period $t + 1$ reference price is now affected

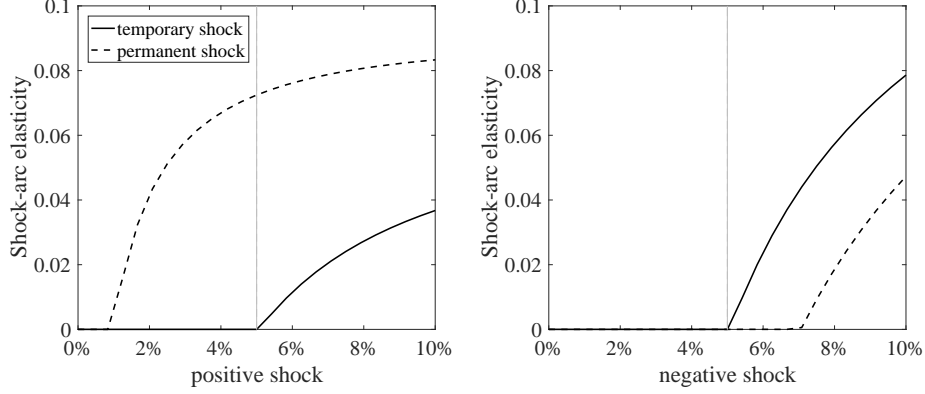


Figure 5: Shock-arc elasticities to positive and negative demand shocks

by the firm's period t pricing decision, i.e. $\frac{\partial R_{t+1}}{\partial P_t} \neq 0$. Thus the firm's price response to the shock differs from that of a myopic firm (which maximizes only its current period profit), as according to the optimality condition (13) the effect of the pricing decision on the reference price drives a wedge between MR_t and MC_t in optimality.

Result 3: *For all permanent shocks, prices are less sluggish upwards than downwards.*

The intuition for this result is as follows: Whereas the firm is assumed to change its price immediately in response to this shock, consumers update their reference price in the following period $t + 1$, i.e. $R_{t+1} = E_t[P_{t+1}|I_t]$. Consequently, for price increases (decreases) the demand curve shifts outwards (inwards) and the kink moves to

$$(\widehat{P}_{t+1}, \widehat{q}_{t+1}) = \left(R_{t+1}, (\tilde{P}_{t+1}/R_{t+1})^\eta y_{t+1} \varepsilon_{t+1} \right). \quad (21)$$

An outward shift of the demand curve (initiated by an upward adjustment in the reference price) increases the firm's long-run profits, whereas an inward shift (initiated by a downward adjustment of the reference price) lowers them. We term this phenomenon the “reference-price updating effect.” The firm can anticipate this. Thus, it may have an incentive to set its price above the level that maximizes its profits in the shock period $P'_t > P_t^*$, therewith exploiting (dampening) the outward (inward) shift of the demand curve resulting from the upward (downward) adjustment of the consumers' reference price for positive (negative) permanent shocks.¹⁶ The firm exploits this effect, as long as the gain from a price rise relative to P_t^* in terms of future profits ($\Pi_{t+1}(R_{t+1} = P'_t) > \Pi_{t+1}(R_{t+1} = P_t^*)$, due to the relative rise in the reference price) exceeds the firm's loss in terms of present profits ($\Pi_t(P'_t) < \Pi_t(P_t^*)$, since the price P'_t is not appropriate for maximizing current profit).

¹⁶Needless to say, setting a price lower than optimal in the shock period with the aim to decrease the reference price permanently is not a preferable option for the firm.

The extend, to which the firm exploits the reference-price updating effect can be seen in Figure 5. The figure shows the shock-arc elasticities of price for temporary (solid lines) and permanent (dashed lines) shocks, given that a shock is positive (left panel) and negative (right panel). The gray vertical lines correspond to the symmetric critical shock size given by equation (15). The reference-price updating effect is measured by the vertical difference between the dashed lines and the solid lines. Figure 5 indicates that in response to a permanent shock the firm significantly exploits the reference-price updating effect and thus generally sets a price that is higher than the price it would optimally set in response to a temporary shock, i.e. $P_t' > P_t^*$. For positive permanent demand shocks this implies that the pricing reaction of the firm is always stronger than for positive temporary demand shocks for both, small and large shocks¹⁷. This can be seen in the left panel of Figure 5, as the dashed line is always on or above the solid line. By contrast, for negative permanent demand shocks the firm adjust its price downward to a considerably lower extent than for negative temporary shocks, as shown in the right panel of Figure 5, where the dashed line is always on or below the solid line. As a consequence, price sluggishness is considerably less pronounced for positive than for negative permanent demand shocks. The asymmetry of the price reaction to positive and negative shocks therefore reverses, when moving from temporary to permanent shocks. While this result may seem surprising at first glance, it is straightforward intuitively: As noted, for temporary shocks, consumers abstract from updating their reference price. Therefore, the firm does not risk to suffer from a downward adjustment of the consumers' reference price, when encountering a temporary drop in demand with a price reduction. On the other hand, for positive temporary shocks, the firm cannot generate permanent increases in demand due to upward-adjustments of the reference price. Since consumers react more sensitive to price increases relative to price decreases, the price and quantity reactions are smaller for positive temporary shocks compared to negative ones. By contrast, for permanent demand shocks, the firm exploits the positive reference-price updating effect which follows from price increases in response to positive shocks, whereas it tries to avoid the negative reference-price updating effect which follows from price decrease in response to negative shocks.¹⁸

Now, consider the marginal cost curve does not cross the midpoint of the marginal revenue gap, but below or above. Figure 6 shows the shock-arc-elasticity of price in the shock-period t for permanent positive and negative demand shocks, for the limit cases, when the marginal cost curve crosses the marginal revenue gap exactly on the upper bound (left panel) and exactly on the lower bound (right panel). As is apparent from Figure 6, while a higher intersection amplifies the downward sluggishness of prices, a lower intersection dampens the downward sluggishness of prices and eventually reverses it. To see the latter result intuitively, consider the limit case when the intersection is exactly on the lower bound. Now, $\bar{\varepsilon}(\gamma) = 0$ and thereby negative shocks

¹⁷Our numerical analysis indicates, however, that the positive reference-price updating effect is never strong enough to invalidate the general result that the pricing reaction of the firm facing loss averse consumers is more sluggish compared to the standard firm.

¹⁸Since the firm avoids price reductions, which lead to downward-adjustments in the reference price, but conducts price reductions, which do not influence the reference price, loss aversion offers a simple rationale for the firm's practice of "sales"(see e.g. Eichenbaum et al., 2011).

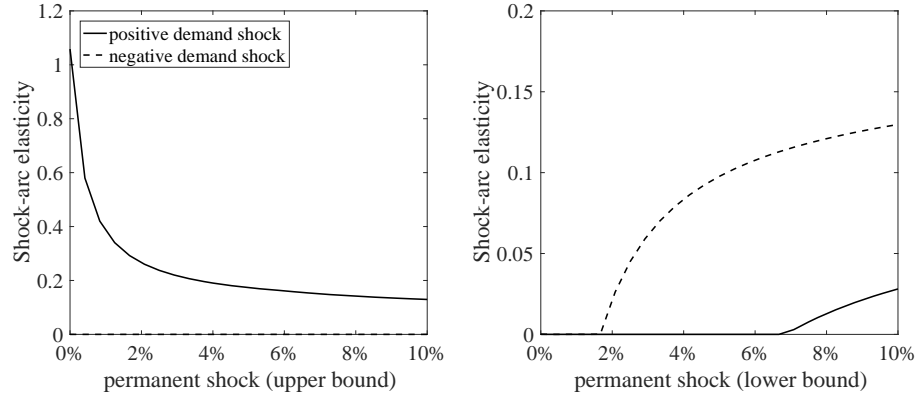


Figure 6: Shock-arc elasticities to positive and negative demand shocks if the marginal cost curve crosses the upper (left panel) and lower (right panel) bound of the marginal revenue gap

are much more likely to have a price effect, whereas $\bar{\epsilon}(\delta) = \max$ and thereby the range of price rigidity in response to positive shocks becomes maximal. Hence, in this case, we have an upward price sluggishness.

Finally, we consider the quantity reactions to permanent demand shocks. Our analysis indicates that quantity declines more in response to negative permanent demand shocks than it increases in response to equiproportionate positive ones. Therefore, as for the large temporary shock, output shows a downward bias. Intuitively, for large permanent negative shocks, prices respond (if at all) only little, so that the shock is absorbed almost exclusively by the negative quantity response. By contrast, for a large permanent positive shock, the price response is disproportionately large, absorbing large parts of the shock and thereby depressing the positive quantity response to the shock.

4.2. Sensitivities

Figure 7 shows the shock-arc elasticities of the price for temporary demand shocks (upper two panels) and permanent demand shocks (lower two panels) for the following values of the loss aversion ratio: $\kappa \in (1.6; 2; 4)$, where our base case is $\kappa = 2$ (solid lines). A loss aversion ratio as low as approximately $\kappa = 1.6$ (dashed lines) was estimated by Kalwani et al. (1990), Hardi et al. (1993), and Kalyanaram and Little (1994), whereas the higher value of 4 (dotted lines) was estimated by Raman and Bass (2002). All estimates are based on a wide variety of frequently used non-durable supermarket products. The solid, dashed, and dotted vertical gray lines denote the critical shock size for $\kappa = 2$, $\kappa = 1.6$, and $\kappa = 4$, respectively.

Figure 7 shows that the higher the loss aversion ratio, ceteris paribus, the more sluggish is price adjustment in response to demand shocks, both upwards and downwards. The shock-arc elasticity curves for higher parameter values always lie below the curves from lower parameter values. This result is independent of whether shocks are temporary or permanent. The critical shocks, positive and negative, increase in the

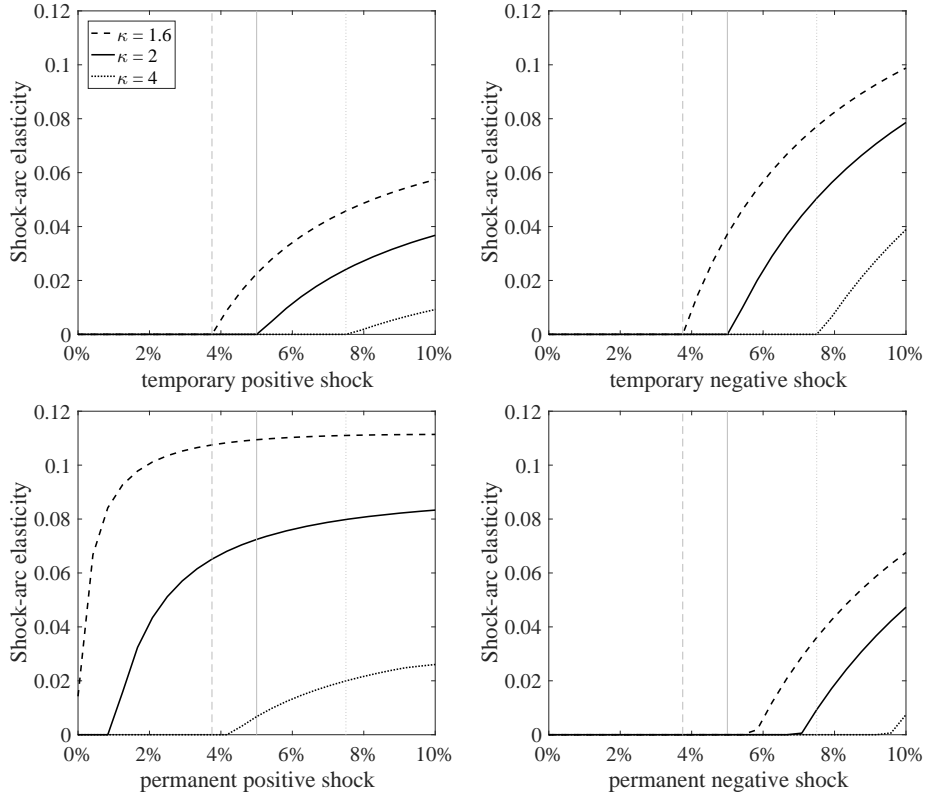


Figure 7: Sensitivity with respect to the loss aversion parameter.

degree of loss aversion and thereby widen the marginal revenue discontinuity. This implies that for both temporary demand shocks and permanent demand shocks, the range of full price rigidity increases as consumers become more loss averse.

The lower right panel of Figure 7 shows that the firms incentive to avoid permanent price cuts increases substantially the more loss averse consumers are. The intuition for this result is straightforward: The higher the price elasticity of demand in the loss domain, the stronger is the resulting decrease of demand due to a downward adjustment of the reference price. Consequently, period $t + 1$ profits decrease. Therefore, the firm's incentive to deviate upwards in response to permanent negative demand shocks increases in the degree of loss aversion. By contrast, for permanent positive demand shocks (lower left panel of Figure 7) the firm's incentive to deviate upwards decreases. Because the reference-price updating effect is stronger, the firm does not necessitate to deviate by as much in order to generate the profit maximizing quantity in period $t + 1$. These responses to permanent positive and negative demand shocks imply that the degree of downward-sluggishness decreases in the degree of loss aversion.

Our sensitivity analysis confirms that over the range of reasonable parameter values for the loss aversion parameter, our theory implies that - in line with the empirical

evidence - prices are more sluggish upwards than downwards in response to temporary demand shocks, while they are more sluggish downwards than upwards in response to permanent demand shocks.

4.3. *Memory-based Mechanisms of Reference Price Determination*

The extent to which the reference price adjusts in response to price changes is crucial for explaining the asymmetric response of prices to positive and negative temporary and permanent demand shocks. In the analysis above, reference prices are expectations-driven. In particular, they do not adjust to temporary demand shocks, but fully to permanent shocks. As an alternative, we consider adaptive or memory-based reference price determination (see Briesch et al. (1997) for a survey), where the degree of past-dependence determines how much the reference price adjusts to a permanent shock. Specifically, the reference price is determined by the current or lagged status quo (Kahneman et al., 1991; Odean, 1998; Genesove and Mayer, 2001). This may include as little as the price from the last purchase occasion (Mayhew and Winer, 1992; Krishnamurthi et al. 1992) or as much as some weighted average of all prices during the entire purchase history (Lattin and Bucklin, 1989; Kalyanaraman and Little, 1994; Mazumdar and Papatla, 1995; Bowman et al., 1999). The former implies that the reference price adjusts quickly to changes in the environment, whereas the latter implies considerable inertia in the adjustment of the reference price. In our model only permanent demand shocks are relevant for reference price adjustments under memory-based reference price determination. Temporary, one-time price changes, by contrast, do not affect the memory-based consumers' reference price (Kalwani and Yim, 1992; Sinha and Smith, 2000; DelVecchio et al., 2007; Lowe et al., 2014).

To analyse the robustness of our results for permanent demand shocks to the reference price updating mechanism, we modify the baseline model as follows. Assume that the reference price is determined by the exponentially smoothed average of past prices (Briesch et al., 1999; Mazumdar et al., 2005; Popescu and Wu, 2007), given by

$$R_{i,t} = \alpha R_{i,t-1} + (1 - \alpha) P_{i,t-1}, \quad (22)$$

where α denotes the degree of past-dependence. For $\alpha = 0$ the reference price adjusts immediately and fully in response to a permanent demand shock in the subsequent period, whereas for $\alpha = 1$ the reference price is exogenously given and remains constant. Using equation (22) and our base calibration from Table 1, we simulate our model numerically under memory-based reference point determination. In the absence of reference price updating ($\alpha = 1$), price responses to permanent demand shocks are upward sluggish and hence, price responses to temporary and permanent shocks coincide. Consequently, the results for the temporary demand shock depicted in the left panel of Figure 3 hold true also for permanent shocks in the case of memory-based reference-price updating with an exogenous reference price. Analogously, with full reference-price adjustment, price responses to permanent shocks under memory-based and expectations-driven mechanisms of reference price determination coincide. Consequently, the results for the permanent demand shock depicted in the right panel of Figure 3 hold true for memory-based reference-price updating with $\alpha = 0$.

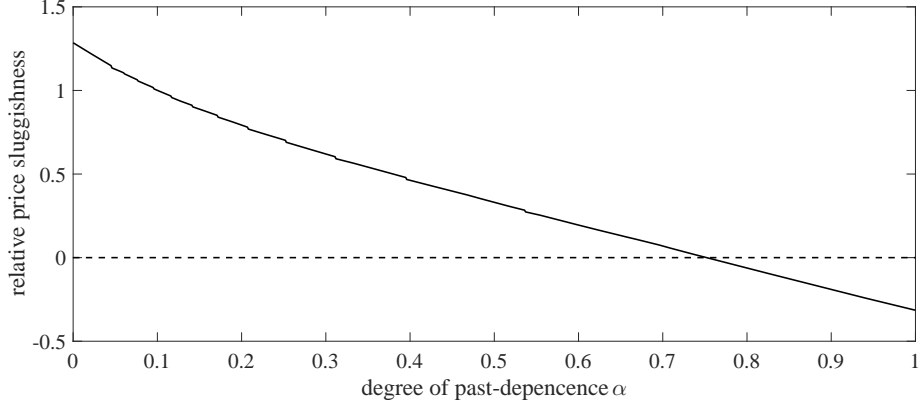


Figure 8: Memory based sluggishness

Figure 8 summarizes how the predictions of our theory for permanent demand shocks depend on the degree of past-dependence. On the vertical axis we show the degree of relative price sluggishness, measured by the cumulative distance between the shock-arc elasticities in response to positive and negative permanent demand shocks from 0-10% for varying values of α . Negative values indicate relative upward price sluggishness and positive values relative downward price sluggishness in response to permanent demand shocks. The horizontal axis measures the degree of past-dependence given by $0 \leq \alpha \leq 1$. We find that prices are downward sluggish for parameter values of past-dependence up to approximately $\alpha < 0.75$, whereas prices are upward sluggish otherwise.

5. Conclusion

In contrast to the standard time-dependent and state-dependent models of price sluggishness, our theory of price adjustment is able to account for empirically relevant asymmetric price responses to positive and negative temporary and permanent shocks of equal magnitude. Beyond the assumption of loss aversion, which enters the utility function, our analysis is fully microfounded. Loss aversion is a well-known empirical phenomenon. In contrast to standard mechanisms of price adjustment, commonly applied in the New Keynesian literature, our explanation of price adjustment does not rely on ad hoc assumptions concerning the frequency of price changes or physical costs of price adjustments. The predictions of our theory are robust to variations in important parameter values and, under reasonable calibration, generalize even in the case of memory-based reference price determination mechanisms.

Our model indicates that positive and negative demand shocks of equal magnitude produce asymmetric price responses and that the sign of the asymmetry depends on the size and the persistence of the underlying demand shock. Our analysis implies that there exists a cutoff point (an intermediate degree of persistence of the shock) at which the asymmetry of price adjustment reverses from upward to downward sluggishness.

For shocks less persistent than this cutoff point, prices are more sluggish upwards than downwards, while they are more sluggish downwards than upwards for more persistent shocks. Whether the degree of persistence at the cutoff point is relatively high or low depends on the adjustment speed of the reference price. An increase in the adjustment speed of the reference price strengthens the role of the reference-price updating effect, increasing upward flexibility and downward sluggishness at any given positive persistence of the shock. To the best of our knowledge, there is no other paper studying the ramifications of the persistence of the demand shock for asymmetric price adjustment in response to small and large positive and negative shocks.

Our model has the following implications for output responses to demand shocks: (1) These responses are symmetric for sufficiently small shocks; (2) For larger shocks, the output responses are greater for negative shocks than for positive ones of equal magnitude, regardless of whether the shocks are temporary or permanent. (3) For positive shocks, the output responses are greater for temporary shocks than for permanent ones. (4) Finally, for negative shocks, the output responses are smaller for temporary shocks than for permanent ones.

From a macroeconomic perspective, the asymmetry of price responses imparts downward pressure on output over the business cycle, interpreted as a sequence of symmetric positive and negative temporary shocks. On the other hand, productivity growth (driven, for example, by technological progress) imparts upward pressure on output, since such growth may be interpreted as a sequence of permanent positive shocks. Our model suggests that the trend of output is the resultant from these two forces.

The predictions of our model also have important implications for the conduct of monetary and fiscal policy. Our analysis suggests that the magnitude of the effects of macroeconomic demand management policy measures depend on whether consumers regard these as temporary or permanent, in particular, whether they are expected to last long enough to induce an update in consumers' reference point or not. Consider, for example, a contraction in government spending, e.g., as part of an austerity program. The output effects of this negative demand shock are larger if firms and consumers believe them to be long lasting, as firms abstain from necessary downward price adjustments to lessen the total negative effect on output. By contrast, if such measures are perceived to be short lived, price reductions occur which lessen the total negative effects on output. Our model implies that - aside from sufficiently small shocks that generate symmetric responses - positive and negative policy shocks have asymmetric effects on prices and quantities. The direction of the asymmetry depends on whether the shock is perceived by consumers as temporary or permanent. The importance of the households' perception of the demand shock opens up another important venue for economic policy makers. It implies that the way policy measures are communicated can have significant influence on the effectiveness of the policy measure.

There are many avenues of future research. Consideration of heterogeneous firms and multi-product firms will enable this model to generate asynchronous price changes, as well as the simultaneous occurrence of large and small price changes, and heterogeneous frequency of price changes across products. Extending the model to a stochastic environment will generate testable implications concerning the variability of individual prices. Furthermore, our model needs to be incorporated into a general equilibrium setting to validate the predictions of our theory.

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