Price Setting in Forward-Looking Customer Markets

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Abstract

We propose a new explanation for price rigidity. If consumers form habits in individual goods, then firms face a time-inconsistency problem. The consumers' habits imply that low prices in the future help attract customers in the present. Firms would therefore like to promise low prices in the future. But when the future arrives they have an incentive to exploit consumers' habits and price gouge. In this model, unlike the standard no-habit model, price rigidity is an equilibrium outcome. Equilibrium price rigidity can be sustained because rigid prices help firms overcome the time-inconsistency problem. If consumers have incomplete information about firms' desired prices, the firm-preferred equilibrium has the firm price at or below a "price cap". Our model therefore provides an explanation for the simultaneous existence of a rigid regular price and frequent sales, a pattern that is difficult to reconcile with existing models of price rigidity. Our model also explains why firms fear adverse reactions to price changes, why sales prices are more flexible than regular prices, why firms make explicit promises not to change prices and why price are more rigid to repeat customers than to one-time customers.

Keywords: Time-inconsistency, Price Rigidity, Habit Formation, Asymmetric Information.

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1 Introduction

A consumer's past purchases of a particular product often exert a strong positive influence on his current demand for this product. Such time non-separability of preferences arise for many different reasons. Some goods are addictive while consumers develop a sense of "brand-loyalty" to others. Consumers favor some products that they have used in the past because of compatibility with other equipment while they favor other products because the quality of competing products is unknown to them. And consumers continue using some products simply because of the large transaction costs associated with switching to a competitor (e.g., another bank or another internet service provider). For all these reasons, it is common for consumers to be partially locked into purchasing a particular product once they have begun purchasing it. Similar lock-in effects are common when firms purchase from suppliers (Shapiro and Varian, 1999).

In this paper, we study the implications that such lock-in effects have for firm price setting. Following Becker and Murphy (1988) and Ravn et al. (2005), we formalize the time non-separability of consumer demand with a model of good-specific habits. We interpret this good-specific habit as providing a reduced form specification for the effects of the various types of switching costs described above as well as capturing the type of addiction studied by Becker and Murphy (1988). We solve for the consumer's demand curve given these preferences and assuming rational expectations. We show that consumer demand is forward-looking; consumer demand depends negatively not only on the current price of the product but also on the consumer's expectations about the good's future prices.

The forward-looking nature of consumer demand implies that firms face a time-inconsistency problem. Since consumers' current demand depends negatively on expected future prices as well as the current price, firms would like to promise that they will keep their prices low in the future. However, when the future arrives and consumers are locked in, the firms have an incentive to renege on their earlier promises and price gouge. The consumers understand these incentives and don't take the firms' promises at face value unless the firms are able to make credible commitments. We show that if firms are not able to make credible commitments this time-inconsistency problem leads them to set prices that are sub-optimally high both from a profit perspective and from the perspective of overall welfare.[1]

[1]The idea that firms have an incentive to price gouge when consumers are locked into a relationship with the

When firms and consumers interact repeatedly, they can improve on this discretionary outcome by entering into "implicit contracts". To formalize this idea, we study the sustainable plans of the infinitely repeated game played by the firm and the consumers (Chari and Kehoe, 1990). We show that implicit contracts involving price rigidity can be sustained as equilibria in our model. The price rigidity entailed by such implicit contracts helps firms partially overcome their incentive to take advantage of consumers' habits. Firms are induced not to deviate from the terms of the implicit contracts by the threat that a deviation would trigger an adverse shift in customer beliefs about the firms' future prices.

We then consider the case in which variables that affect the firm's pricing problem—such as its marginal costs and the demand for its products—are unobservable or too costly for the firm's customers to observe. In the standard no-habit model, this is irrelevant since consumer demand is determined solely by the firm's current price. However, in the habit model, asymmetric information limits the variables that it is possible, even in principle, for the firm and customers to make use of in implicit contracts. We use the results of Athey et al. (2004) to show that the most desirable sustainable price path from the firm's perspective under this kind of asymmetric information takes the form of an implicit contract that limits the firms discretion by setting a "price cap" above which the firm cannot set its price. Under this policy, the firm acts with discretion when its marginal costs and demand are relatively low; but sets its price equal to the price cap when marginal costs and demand are high. The price cap has the beneficial effect that it lowers the customers' expectations about future prices and thereby increases demand. Given plausible assumptions about the process followed by the firm's desired price and the extent of informational asymmetries, the firm's price will be "stuck" at the price cap a significant fraction of the time. It will, however, frequently drop below the price cap and exhibit much more flexibility when it is not at the price cap.

The time-inconsistency problem that firms face implies that there is a fundamental difference between our model and the more standard "no-habit" model. In the no-habit model, there is a unique equilibrium in which prices are flexible. In our model, there are many implicit contracts that give rise to sustainable price paths. Some of these contracts will entail nominal rigidity. Whether nominal rigidities occur is therefore a matter of equilibrium selection in our model. In other models

firm has been explored in Cremer (1984), Farell and Shapiro (1989), Klemperer (1995), Bagwell (2004) and Caminal (2004). Our model differs substantially from the models considered in these papers. Furthermore, we focus on very different implications of this fact.

in the literature nominal rigidities only arise as a consequence of some real friction such as menu costs.

The model we analyze is a model of "customer markets". The seminal paper on customer markets is Phelps and Winter (1970).[2] An important drawback of the earlier literature on customer markets is that customers' demand curves are not derived from the behavior of forward-looking, optimizing agents. We show that the conclusions of the customer markets literature change substantially once the forward-looking nature of customers is taken into account.

Explaining price rigidity was a major motivation for the original development of customer markets models. According to Okun's (1981) "invisible handshake" version of the customer markets idea, firms have implicit agreements with their customers not to take advantage of tight market conditions by raising their price in exchange for stable prices in weak markets. This view of price rigidity finds strong support in the views of firm managers. When managers of U.S. manufacturing firms were asked why they don't change their prices more often than they do, by far the most frequent answer they gave was that they feared that this would "antagonize" their customers (Blinder et al., 1998). Similar surveys in a host of other countries have since confirmed that the most important reason cited by firm managers for price rigidity is that they are loathe to "damage customer relations" by changing their prices.[3] Furthermore, Levy and Young (2004, 2005) present direct evidence from company documents on the importance of implicit contracts.

The problem with this explanation for price rigidity has been that the customer markets literature has not provided a convincing rationale for why firms enter into these implicit contracts with their customers. Our model suggests that firms may be trying to build and maintain a reputation for not taking advantage of locked-in customers. In other words, prices may be rigid because firms are trying to "commit to a sticky price".

We explore a number of empirical predictions of our model. First, the asymmetric information version of our model has the following empirical prediction: Goods prices should spend a significant

[2]Other contributions include Okun (1981), Bils (1989), Rotemberg and Woodford (1991, 1995), Bagwell (2004) and Ravn et al. (2005).

[3]See Apel et al. (2004) for a survey of Swedish firms; Hall et al. (1997) for U.K. firms; Amirault et al. (2004) for Canadian firms; and Fabiani et al. (2004) for a meta-study of surveys of firms in Belgium, Germany, Spain, France, Italy, Luxembourg, the Netherlands, Austria and Portugal. A consistent finding across these surveys is that firms rate implicit and explicit contracts as the most important (or, in a few cases, among the most important) sources of price rigidity. In contrast, menu-costs and information costs typically rank rather low among the reasons for price rigidity. Fabiani et al. (2004) is particularly noteworthy due to its size (over 10,000 respondents) and scope (nine countries and many different sectors).

portion of their time at a rigid upper bound. Below this upper bound, they should be much more flexible. As the reader is no doubt aware from casual observation, two of the most salient features of retail price series are the existence of a "regular" price, which remains unchanged for long periods of time, and frequent "sales"—i.e., brief periods during which the price drops below its regular price before returning back to the old regular price.[4] In section 5, we document these features of retail prices formally using the Dominick's Finer Foods dataset provided by the University of Chicago Graduate School of Business. We furthermore show that sales prices are about 8 times more flexible than regular prices.

To date, price rigidity and the existence of frequent sales have been studied separately. In macroeconomics, there is a large literature on price rigidity. This literature has focused on the notion that there may be costs associated with changing prices.[5] The large number of sales observed in retail price data and the fact that prices frequently return to the old regular price after sales is difficult to reconcile with such menu cost models. In applied microeconomics and industrial organization there is a large literature seeking to understand sales.[6] The models in this literature cannot account for the existence of a rigid regular price that truncates the price distribution from above without making special assumptions about consumer valuations. Our model is the only model of rational agents we are aware of that endogenously generates both rigid regular prices and frequent sales.[7]

A second type of empirical evidence presented in section 5 pertains to company announcements about their prices. We present numerous quotes from firms' marketing rhetoric in which they promise customers not to increase prices, sometimes with the stated goal of not adversely affecting consumers' expectations about future prices. In the context of the standard no-habit model, it is difficult to rationalize why firms would self-impose restrictions on their future prices in this way. In the context of the habit model we present, however, such announcements are quite natural. Firms

[4]See figures 1-3 for examples of this pattern.

[5]Empirical studies of price rigidity include Carlton (1986), Cecchetti (1986), Kashyap (1995), Blinder et al. (1998), Bils and Klenow (2004), Klenow and Kryvtsov (2005) and Konieczny and Skrzypacz (2005). Contributions to the literature on menu costs include Barro (1972), Akerlof and Yellen (1985), Mankiw (1985), Caplin and Spulber (1987) and Golosov and Lucas (2005). Levy et al. (1997) provides estimates of the size and form of menu costs.

[6]Contributions to the literature on sales include Salop (1977), Varian (1980), Salop and Stiglitz (1982), Conlisk et al. (1984), Sobel (1984), Lazear (1986), Pashigian and Bowen (1991), Warner and Barsky (1995), Aguirregabiria (1999), Hosken et al. (20000), Pesendorfer (2002), Chevalier et al. (2003) and Hendel and Nevo (2003).

[7]Rotemberg (2004) presents a model in which consumers become angry if they perceive firm pricing to be unfair. He shows how this model is consistent with both price rigidity and temporary sales.

make these announcements as part of their efforts to manage the expectations of their customers. Specifically, in an effort to convince consumers that the firm will not take advantage of them in future periods.[8]

Third, we discuss a number of existing empirical results that support our model of price rigidity. In particular, we discuss experimental evidence supporting the notion that prices are stickier in customer markets. We also discuss empirical work showing that prices to new customers are less rigid than prices to old customers.

We build heavily on recent work by Ravn et al. (2005). While the primary focus of their paper is a model of good specific external habits, they also derive consumer demand in the case of good specific internal habits. They note that in the internal habits model the firm faces a time inconsistency problem but leave for future research a detailed analysis of the firm's pricing problem in this case. Our paper focuses on analyzing this problem.

The paper proceeds as follows: In section 2, we illustrate the basic time-inconsistency problem that arises due to consumer habit formation in the context of a deterministic two period model. In section 3, we extend the model to the infinite horizon and consider stochastic variation in both marginal costs and demand. We also present results about the sustainability of implicit contracts that entail nominal rigidity. In section 4, we consider the case in which firms have private information about their marginal costs and demand. In section 5, we present empirical evidence supporting our model. Section 6 concludes.

2 A Deterministic Two-Period Model

Consider a two-period economy in which there are a continuum of firms of measure one each of which produces a differentiated good. Consumers' preferences over the consumption of these goods are given by

$$U(C_1) + \beta U(C_2)$$

where

$$C_1 = \left[\int_0^1 (c_1(z) - \gamma c_0(z))^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}, \tag{1}$$

[8] Zbaracki et al. (2004) document large costs associated with convincing customers of the logic of a price change to prevent price changes from antagonizing customers.

$$C_2 = \left[\int_0^1 (c_2(z) - \gamma c_1(z))^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}, \tag{2}$$

$c_j(z)$ denotes the consumption of good z at time j, θ determines the elasticity of substitution between goods, β is the consumer's discount factor. This utility function implies that consumers' utility from the consumption of a particular good is not time separable. Rather, the utility a consumer derives from good z in a particular period depends not only on his level of consumption in that period but also on how much he consumed of this good in the previous period. In other words, the consumer has a habit in each of the differentiated goods.[9] The parameter γ is a measure of the degree of this good-specific habit. We assume that $0 \leq \gamma \leq 1$.[10]

The consumers face two types of decisions about consumption. They must decide how to divide their income between consumption in period 1 and consumption in period 2 and they must decide how to allocate their spending at each point between the different goods. Given a choice for C_1 and C_2, it is optimal for the consumers to choose $c_1(z)$ and $c_2(z)$ to minimize expenditures. In other words, they should minimize

$$\int_0^1 p_1(z)c_1(z)dz + M \int_0^1 p_2(z)c_2(z)dz$$

subject to equations (1) and (2), where $p_j(z)$ denotes the price of good $c_j(z)$ denominated in dollars and M denotes the period 1 price of a dollar in period 2.

The first order conditions of this problem yield the following demand curves:

$$c_1(z) = \gamma c_0(z) + C_1 \left(\frac{p_1(z) + \gamma M p_2(z)}{P_1} \right)^{-\theta}, \tag{3}$$

[9]Equations (1) and (2) with constant θ imply that the consumer's marginal utility from good z rises to infinity as his consumption of this good falls toward its habit level. In other words, the habit level is a subsistance point for the consumer in good z. A positive subsistence level implies that firm z can attain arbitrarily high profits by raising its price high enough. To rule out this extreme outcome, we assume that θ is constant for all values of $c_t(z) - \gamma c_{t-1}(z) > c^*$. For smaller values of $c_t(z) - \gamma c_{t-1}(z)$, the θ within the integral varies by good and goes to infinity as consumption of good z falls towards its habit level so that the consumer's marginal utility from good z remains small enough to guarantee that it is unprofitable for the firm to drive the consumer to his habit level of consumption in good z. This argument and the fact that these complications don't otherwise affect the solution of the model are made precise in a technical appendix which is available upon request. A similar deviation from CES preferences is needed to rule out unbounded prices in Ravn et al. (2005).

[10]By assuming that $\gamma \geq 0$, we are focusing on goods for which a consumer's past purchases exert a *positive* influence on current demand. While this is true for many goods, there also exist goods for which a consumer's purchases in the recent past *negatively* influence current demand. This is true, e.g., for many durable goods. For such goods, the model presented in this section with $\gamma < 0$ may imply a reasonable reduced form model for consumer demand. To the extent that this is the case, the results of our model hold for this class of goods as well as the class of goods we focus on. See footnotes 17 and 19 for a more detailed discussion of what our model implies in the $\gamma < 0$ case.

and

$$c_2(z) = \gamma c_1(z) + C_2 \left(\frac{p_2(z)}{P_2} \right)^{-\theta}, \tag{4}$$

where P_1 and P_2 denote the price levels in periods 1 and 2.[11] Notice that when $\gamma = 0$ these demand curves reduce to iso-elastic Dixit-Stiglitz demand curves. When $\gamma \neq 0$, consumer demand differs from this simple benchmark in two ways. First, demand depends on demand in the previous period. Second, demand in period 1 is influenced not only by $p_1(z)$ but also by $p_2(z)$. The intuition for these two effects is straight-forward. When the consumer has a habit, his flow utility at a given point in time depends directly on his consumption in the previous period. His demand in a given period therefore depends on his consumption in the previous period. However, the consumer also understands that by consuming a particular good in period 1 he is increasing his habit in this good, thereby increasing his future demand for it. As a consequence, the consumer's demand in period 1 is affected by how costly it will be to feed his habit in period 2, i.e., his demand in period 1 depends on the price of the good in period 2.

Next consider the pricing decision of firm z. The fact that consumer demand in period 1 depends on $p_2(z)$ implies that the firm faces a time-inconsistency problem. In order to demonstrate this, we compare the firm's behavior with commitment to its behavior with discretion. In both cases we restrict attention to subgame perfect equilibria of the game between firm z and the consumers. In order to keep the analysis as simple as possible, we assume that $c_0(z) = 0$.

2.1 Commitment

Consider the following timing of events. At the beginning of period 1, the firm chooses both $p_1(z)$ and $p_2(z)$. The consumers then choose $c_1(z)$. Finally, in period 2, the consumers choose $c_2(z)$. The crucial assumption is that the firm is able to set $p_2(z)$ before consumers choose $c_1(z)$ and it can't renege on this choice in period 2. This assumption about timing amounts to assuming that the firm has access to a commitment technology that ties its hands in period 2. We refer to this as the commitment case and say that the firm acts with commitment when this is the timing of events.

In the commitment case, the firm maximizes profits given by

$$\Pi_1(z) = (p_1(z) - W)c_1(z) + M(p_2(z) - W)c_2(z), \tag{5}$$

[11] P_1 is the index of individual prices that has the property that $P_1 C_1$ is the minimum expenditure required to achieve a utility level C_1. P_1 is also the Lagrange multiplier in the consumer's constrained expenditure minimization problem.

subject to

$$c_1(z) = C_1 P_1^{\theta}(p_1(z) + \gamma M p_2(z))^{-\theta}, \tag{6}$$

$$c_2(z) = \gamma c_1(z) + C_2 P_2^{\theta} p_2(z)^{-\theta}, \tag{7}$$

where we have assumed that the firm faces constant marginal costs of production equal to W. Let $p_1^c(z)$ and $p_2^c(z)$ denote the prices charged by the firm in the commitment case.[12] We state the solution to the firm's problem as our first proposition.

Proposition 1. *When the firm can act with commitment, it sets*

$$p_1^c(z) = \tfrac{\theta}{\theta-1} W \quad \textit{and} \quad p_2^c(z) = \tfrac{\theta}{\theta-1} W. \tag{8}$$

Proof: See Appendix A. ■

Notice that the price set by the firm under commitment is independent of the degree of habit γ. In other words, the fact that consumers form habits has no effect on the price setting behavior of the firm if the firm is able to make credible commitments about its future prices.

2.2 Discretion

Now consider an alternative timing of events in which the firm and the consumers act sequentially. In each period the firm first chooses what price to charge and then the consumer chooses how much to purchase of the good. The important difference between this case and the commitment case is that in this case the consumer chooses $c_1(z)$ before the firm chooses $p_2(z)$. We refer to this case as the discretion case and say that the firm acts with discretion when this is the timing of events.

We can solve the firm's problem when it acts with discretion by backward induction. In period 2, the firm maximizes $\Pi_2(z) = (p_2(z) - W)c_2(z)$ subject to equation (7). Equivalently, the firm maximizes

$$\Pi_2(z) = (p_2(z) - W)(\gamma c_1(z) + C_2 P_2^{\theta} p_2(z)^{-\theta}), \tag{9}$$

where we have used equation (7) to eliminate $c_2(z)$ from the expression for $\Pi_2(z)$.

[12] Below, superscript c's on other variables will be used to denote the equilibrium values of these variables under commitment.

In period 1, the firm maximizes Π_1, given by equation (5), with respect to $p_1(z)$, subject to equations (6)-(7) and taking $p_2(z)$ as given. Equivalently, the firm maximizes

$$\Pi_1 = (p_1(z) - W)C_1 P_1^{\theta}(p_1(z) + \gamma M p_2(z))^{-\theta} \\ + M(p_2(z) - W)(\gamma C_1 P_1^{\theta}(p_1(z) + \gamma M p_2(z))^{-\theta} + C_2 P_2^{\theta} p_2(z)^{-\theta}) \tag{10}$$

with respect to $p_1(z)$, taking $p_2(z)$ as given.

Let $p_1^d(z)$ and $p_2^d(z)$ denote the price charged by the firm in the discretion case and superscript d's on other variables denote the equilibrium values of these variables in the discretion case. Then the following proposition describes the solution of the firm's problem when it acts with discretion.

Proposition 2. *When $0 < \gamma \leq C_2/C_1$ and the firm acts with discretion:*

1) The firm sets $p_2^d(z) > p_2^c(z)$. Furthermore, $\partial p_2^d(z)/\partial\gamma > 0$.

2) The firm sets $p_1^d(z) < p_1^c(z)$, such that $c_1^d(z) = c_1^c(z)$;

3) $\Pi^d(z) < \Pi^c(z)$.

Proof: See Appendix A. ■

The main result embodied in Proposition 2 is that when consumers form habits the firm faces a time-inconsistency problem which leads it to set a price that is "too high" in period 2. This problem arises because in this case consumer demand in period 1 depends negatively on $p_2(z)$ as well as $p_1(z)$. This means that in period 1, the firm has an incentive to try to raise current demand by promising that its future price will be low. However, when the future arrives, the firm has an incentive to renege on its earlier promise and take advantage of the consumers habit by "price gouging".

Proposition 1 shows that when the firm is able to commit not to renege on its promises it optimally sets its price in period 2 as if the consumer didn't have any habit. Proposition 2 shows that when the firm can not make such commitments the firm exploits the consumer's habit in period 2 by setting a higher price than it would if it were able to make commitments. The consumers, of course, understand that the firm will behave in this way. The high price in period 2 therefore lowers demand in period 1. It is optimal for the firm to respond to this by lowering its price in period 1 just enough to keep demand in period 1 unchanged. The overall effect of the firm's inability to make credible commitments is to lower its profits.

2.3 Menu Costs

The idea that firms face menu costs and other barriers to price changes is arguably the most important idea used by macroeconomists to explain price rigidity.[13] Price rigidity is in turn a crucial feature of most models of monetary non-neutrality. The standard view in the literature is that the existence of menu costs hurt firms. Firms therefore have an incentive to adopt technologies that make changing prices easy and cheap. For this reason, one might believe that menu costs must be small. To many, the most compelling argument for menu costs as a source of monetary non-neutrality is therefore the fact that small menu costs can imply large amounts of monetary non-nutrality (Akerlof and Yellen, 1985; and Mankiw, 1985).

The existence of a time-inconsistency problem in the habit model discussed above implies a dramatically different view of menu costs. In the habit model, menu costs can be beneficial to a firm since they can help the firm overcome its incentive to price gouge in the second period. To see this formally, consider an environment in which the firm and its consumers act sequentially as in the discretion case. But assume that the firm has to pay a fixed cost τ if it chooses to change its price in the second period. Denote the prices chosen by the firm in this environment by $p_1^m(z)$ and $p_2^m(z)$. We then have the following result.

Proposition 3. *If* $\tau > \underline{\tau}$, $p_1^m(z) = p_1^c(z)$ *and* $p_2^m(z) = p_2^c(z)$.

Proof: See Appendix A. ■

Proposition 3 shows that in the simple model with good-specific habit analyzed in this section a menu cost can fully alleviate the firm's time-inconsistency problem and allow it to attain the same level of profits as if it were able to make credible commitments. This implies that in markets in which time-inconsistency problems due to consumer lock-in are important firms have an incentive to intentionally adopt technologies and an organizational structure that make changing prices costly. This is consistent with evidence that firms review their prices infrequently—often only once or twice a year—and that this review process is quite elaborate and time consuming (Blinder et al., 1998; and Zbaracki et al., 2004;).

The result that a menu cost can allow the firm to attain the fully optimal commitment outcome

[13] In following discussion, we use the term "menu costs" to refer not only to physical menu costs but also other barriers to price changes such as information gathering costs, decision-making costs, communications costs and the costs of negotiating with customers (Levy et al., 1997; Zbaracki et al. 2004).

is somewhat special to the model presented in this section. In a more elaborate model with, e.g., variations in costs and demand, menu costs help the firm overcome its time-inconsistency problem but prevent the firm from letting its price respond optimally to variations in market conditions. In such a model, menu costs are beneficial to a firm if the benefits of overcoming the time-inconsistency problem outweigh the costs of inefficient responses to shocks. Whether this is the case, will depend on the severity of the time-inconsistency problem and the volatility of market conditions.

3 A Stochastic Infinite Horizon Model with Complete Information

The simple setting analyzed in section 2 is well suited to illustrate the basic time-inconsistency problem that firms face when consumers form good-specific habits as well as the fact that firms can benefit from menu costs in this case. However, in order to be explore other important features of price setting when consumers form good-specific habits we need to develop an infinite horizon model in which demand and marginal costs vary stochastically over time.

3.1 Consumer Demand

Consider the following infinite horizon extension of the model analyzed in section 2. Consumers' preferences are given by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t),$$

where

$$C_t = \left[\int_0^1 (c_t(z) - \gamma c_{t-1}(z))^{\frac{\theta_t - 1}{\theta_t}} dz \right]^{\frac{\theta_t}{\theta_t - 1}}, \tag{11}$$

and E_0 denotes an expectations operator conditional on information at time t. Apart from expanding the time horizon, we have extended the model by allowing θ_t to vary stochastically over time. The time variation in θ_t should be viewed as a stand-in for all time varying features of demand that affect the firm's optimal price and that are not explicitly modeled.

As in the two period model, consumers face two types of decisions about consumption. They must decide how much to spend on consumption at each point in time and how to allocate their spending at each point between the different goods. These two problems may be analyzed separately. We focus on the allocation of spending across goods at a particular point in time. Given a state contingent path for total consumption $\{C_{t+j}\}_{j=0}^{\infty}$, the consumers seek to minimize their expenditures. Formally, the consumers choose $c_t(z)$ to minimize

$$E_t \sum_{j=0}^{\infty} M_{t,t+j} \int_0^1 p_{t+j}(z) c_{t+j}(z) dz$$

subject to $\{C_{t+j}\}_{j=0}^{\infty}$, where $M_{t,t+j}$ denotes the stochastic discount factor that the consumers use to value future cash flows.

The solution to this optimization problem implies that consumer demand for good z is

$$c_t(z) = \gamma c_{t-1}(z) + C_t \left(\frac{E_t \sum_{j=0}^{\infty} \gamma^j M_{t,t+j} p_{t+j}(z)}{P_t} \right)^{-\theta_t}. \tag{12}$$

As in the two period model, current demand is inversely related not only to the current price but also to expected future prices. In this case current demand depends on an infinite sum of discounted expected future prices.

3.2 The Firm's Objective

Firm z seeks to maximize its value,

$$E_0 \sum_{t=0}^{\infty} M_{0,t} [p_t(z) c_t(z) - W_t L_t(z)], \tag{13}$$

subject to the constraint that it produces at least as much as it sells,

$$c_t(z) \leq A_t f(L_t(z)), \tag{14}$$

and subject to the demand for its product, given by equation (12). Here A_t denotes an exogenous random technology factor, $L_t(z)$ denotes the firm's labor demand and W_t denotes the exogenous random wage paid by the firm to its employees.

3.3 Commitment

As in section 2, we begin by analyzing a situation in which the firm is able to make commitments about future prices. More precisely, we assume that at the beginning of period 0 the firm chooses a state-contingent path for it price for all future periods. We assume that the firm has access to a commitment device that prevents it from reneging on these choices in future periods. In this case we have the following result about the firm's optimal pricing policy.

Proposition 4. *If $\theta_t = \theta$ for all $t \geq 0$ and the firm can commit at time 0 to a fully state-contingent path for future prices, it sets its price in period $t \geq 1$ equal to a constant markup over marginal cost,*

$$p_t(z) = \frac{\theta}{\theta - 1} S_t \tag{15}$$

where $S_t = W_t / A_t f'(L_t(z))$.

Proof: See Appendix A. ■

This result contrasts the results of earlier customer market models based on ad hoc demand specifications such as those in Phelps and Winter (1970) and Rotemberg and Woodford (1991, 1995). In Phelps and Winter (1970) firms optimally vary their price less than one for one with marginal costs. Thus, markups vary countercyclically. In Rotemberg and Woodford (1991, 1995) the cyclicality of markups is in general ambiguous but they vary procyclically in the case the authors focus on.[14] The idea that motivates the demand specifications assumed in these papers is that consumers respond sluggishly to changes in prices—due to switching costs and habits. Firms can invest in their "customer base" by lowering their current price. Likewise, by raising their price, firms not only lower current demand but also erode their customer base thereby negatively affecting future demand.

The crucial difference between our model and earlier customer markets models is that in our model consumers realize that their demand in future periods depends on their actions in the current period. This entails that consumers decide to become customers of a particular firm not only based on the current price of the firm's product but also based on their expectations about its future prices. In contrast, the earlier customer market literature assumes that changes in a firm's market share are a function only of the firm's current price. This assumption is not consistent with the interpretation that consumer's sluggish responses are due to switching costs. Surely consumers realize that if they become customers of a particular firm they will become partially locked into that relationship in the future. Equation (4) shows that, given the consumption aggregator (11), it is optimal for a firm facing forward looking consumers to let its price vary one-for-one in percentage terms with marginal costs.

[14] Ravn et al. (2005) show that a model in which consumers have good-specific *external* habit yields a consumer demand function closely related to the one assumed in the earlier customer markets literature. In their model markups vary countercyclically.

3.4 Discretion

Now consider the case in which the firm and consumers act sequentially. At the beginning of each period the firm sets the price of its product for that period. The consumers then choose how much to demand. The firm does not have access to a commitment device. We furthermore focus on equilibria in which the firm's price is not contingent on its past actions or past exogenous shocks, i.e. Markov perfect equilibria. In the macroeconomics literature, this case is often referred to as the discretionary case. In section 3.5, we consider the larger set of equilibria in which the firm's price may depend on its own past actions as well as current and past exogenous shocks.

Solving analytically for sustainable plans under discretion is intractable in general. We therefore resort to approximation methods of the sort that are widely used in monetary economics (see, e.g., Woodford, 2003; and Benigno and Woodford, 2004). We approximate the firm's problem around its steady state solution with commitment and assume that exogenous shocks and the habit coefficient, γ, are small. In addition, we make several simplifying assumptions about functional form: We assume that the firm's production function is linear; and that W_t, A_t and θ_t are i.i.d..

Given these assumptions, we show in appendix B that a second order approximation of the firm's value is

$$E_0 \sum_{t=0}^{\infty} p(z)c(z)\beta^t \left[\left(\hat{p}_t(z) + \frac{1}{2}\hat{p}_t(z)^2 \right) + \frac{1}{\theta}\left(\hat{c}_t(z) + \frac{1}{2}\hat{c}_t(z)^2 \right) + \hat{p}_t(z)\hat{c}_t(z) \right.$$
$$\left. - \frac{\theta - 1}{\theta}\hat{S}_t\hat{c}_t(z) + \hat{p}_t(z)\hat{M}_{0,t} + \frac{1}{\theta}\hat{c}_t(z)\hat{M}_{0,t} \right], \qquad (16)$$

where $\hat{c}(z) = \log(c_t(z)/c(z))$, hatted versions of other variables are defined analogously and $\hat{S}_t = (\hat{W}_t - \hat{A}_t)$ denotes percentage deviations of marginal cost from steady state. A second order approximation of the consumer demand curve is

$$\left(\hat{c}_t(z) + \frac{1}{2}\hat{c}_t(z)^2 \right) - \gamma\hat{c}_{t-1}(z) - \frac{1+\theta}{2\theta(1-\gamma)}\hat{c}_t(z)^2 - \theta\hat{P}_t - \hat{C}_t + \hat{P}_t\hat{c}_t(z)$$
$$+ \frac{1}{\theta}\hat{C}_t\hat{c}_t(z) + (\theta - 1)\hat{c}_t(z)\hat{\Upsilon}_t = -\theta(1 - \gamma - \gamma\beta)\hat{p}_t(z) - \frac{\theta}{2}\hat{p}_t(z)^2 + \gamma\beta E_t\hat{c}_{t+1}(z), \quad (17)$$

where $\hat{\Upsilon}_t = -\hat{\theta}_t/(\theta - 1)$ and we have dropped exogenous second order terms, since they do not affect the analysis below.

First, as a point of reference, we derive the optimal price plan of a firm that is able to make commitments.

Lemma 1. *If the firm can commit at time 0 to a fully state-contingent path for future prices, it sets its price in period* $t \geq 1$ *to* $\hat{p}_t^c(z) = \hat{S}_t + \hat{\Upsilon}_t$.

Proof: See Appendix A. ■

Lemma 1 differs from Proposition 4 since it is based on the approximate described above and also because we are allowing for exogenous variation in θ_t. In this case, the firm's optimal price responds not only to variations in marginal costs but also to demand side variations in $\hat{\Upsilon}_t$. As we noted before, $\hat{\Upsilon}_t$ is meant to be a stand-in for demand-side features that affect the firm's optimal price but are not modeled explicitly.

Returning to the case in which the firm is unable to make commitments, the Markov perfect (also referred to as the "discretionary" or static) equilibrium is characterized in Proposition 5.

Proposition 5. *In the unique Markov perfect equilibrium, the firm sets its price to*

$$\hat{p}_t^m(z) = \frac{\gamma}{\theta - 1} + \hat{S}_t + \hat{\Upsilon}_t, \tag{18}$$

Proof: See Appendix A. ■

The positive constant term in equation (18) implies that in the Markov perfect equilibrium the firm sets a higher price on average than it does when it can make commitments. The higher price implies a lower demand and lower profits for the firm. The higher price, of course, also hurts consumers. Social welfare is therefore also lower in the Markov perfect equilibrium than when the firm can make state-contingent commitments.

3.5 Implicit Contracts as a Substitute for Commitment

When consumers and firms interact repeatedly, the firm may be able to overcome its time-inconsistency problem even if it is unable to make commitments by what is often referred to as reputation formation but in this context might be called an implicit contract with its consumers (Okun, 1981). These implicit contracts sustain equilibria in which the firm is induced not to take advantage of its customers' habits by the threat that doing so would trigger an adverse shift in customer beliefs about its future behavior.

As in section 3.4, we assume that the firm and consumers act sequentially and we don't endow the firm with any ability to make commitments. However, in this section, we consider equilibria in which the firm's price may be contingent on its own past actions as well as current and past exogenous shocks. We then look for *sustainable plans*, i.e., price plans for the firm that (along with the corresponding consumption choices by consumers) constitute symmetric sequential equilibria of the game between the firm and consumers.

Many such sustainable price plans exist. In particular, if the firm is sufficiently patient the pricing policy chosen by the firm under commitment can be sustained by an implicit contract. Proposition 6 formalizes this idea.

Proposition 6. *If $\beta > \underline{\beta}$, the following price path is a sustainable plan: At time 1, set $\hat{p}_1(z) = \hat{p}_1^c(z)$. At time $t > 1$, set $\hat{p}_t(z) = \hat{p}_t^c(z)$ if $\hat{p}_\tau(z) = \hat{p}_\tau^c(z)$ for all $0 < \tau < t$. Otherwise set $\hat{p}_t(z) = \hat{p}_t^m(z)$.*

Proof: See Appendix A. ■

We interpret this price path as an implicit contract between the firm and the consumers. The implicit contract involves a trigger strategy. If the firm deviates from $p_t^c(z)$, consumers believe that the firm will set its price as in the Markov perfect (discretionary) equilibrium from then on. This adverse shift in consumer beliefs induces the firm not to deviate from $p_t^c(z)$.

A prominent stylized fact about most goods prices is that they exhibit nominal rigidity (Bils and Klenow, 2004). In the standard no-habit model, nominal rigidity does not arise as an equilibrium outcome. In contrast, when consumers form habits in specific goods, nominal rigidity can arise as an equilibrium outcome. Proposition 7 characterizes a simple sustainable plan with two period nominal rigidity.

Proposition 7. *Assume that $\beta > \underline{\beta}$ and*

$$\gamma^2 > (\theta - 1)^2 \frac{1 + \beta - \beta^2}{2\beta + \beta^2} var(\hat{S}_t + \hat{\Upsilon}_t). \tag{19}$$

The following price path is a sustainable plan: Set

$$\hat{p}_t(z) = \frac{\gamma}{(\theta - 1)(1 + \beta)} + \frac{1}{1 + \beta}(\hat{S}_t + \hat{\Upsilon}_t). \tag{20}$$

in periods $t \in \{1, 3, 5, ...\}$ and do not change the price in the even numbered periods as long as all past prices have been set in this way. Otherwise, set $\hat{p}_t(z) = \hat{p}_t^m(z)$.

Proof: See Appendix A. ■

This price path may be viewed as an implicit contract between the firm and its consumers which stipulates: 1) The firm's prices should remain fixed for 2 periods at a time; and 2) If the firm ever deviates from this, consumers expect the firm to set its price as in the Markov perfect equilibrium from then on. In fact, this is the firm-preferred price path given this type of trigger strategy by the consumers.[15] The firm can be induced not to deviate from this implicit contract because the price rigidity it entails helps the firm partially overcome its incentive to price gouge. Notice that the constant term in equation (20) is smaller than the constant term in equation (18). The firm sets a lower average price in this case because a high price in period t raises consumer's expectations about the firm's price in period $t+1$ and therefore raises the consumer's cost of forming a habit in the good. Against this benefit, the firm must weigh the cost of price inflexibility. Since the firm can only change its price every other period, it is not able to respond optimally to fluctuations in marginal costs and demand. Instead of responding one-for-one in percentage terms to variations in marginal costs and demand as in equation (18), the firm only changes its price by $1/(1+\beta)$ percent for each percentage point deviation in marginal costs or demand. Condition (19) determines how strong the consumers' habit must be for the commitment benefit to outweigh the costs of inflexibility.

Our model suggests that price rigidity may be due to implicit contracts between firms and consumers. This idea finds a great deal of support in survey data. In Blinder et al. (1998), 64.5% of firms report that they have implicit contracts with their consumers and an overwhelming majority of these firms (79%) indicate that these implicit contracts are an important source of price rigidity. Surveys in many other countries have since confirmed this result (see footnote 3). Furthermore, the punishment phase of such implicit contracts provides an interpretation for consumers' adverse reactions to price increases that are not justified by observable increases in costs. Consumers often perceive such price increases as "unfair" (see, e.g., Kahneman et al., 1986; and Rotemberg, 2002 and 2004). If firms and consumers enter into implicit contracts, it is exactly these types of price increases that lead to adverse reactions by customers.

Many other implicit contracts yield sustainable price paths. Some entail nominal rigidity and others don't. Whether nominal rigidities occur is therefore a matter of equilibrium selection in our model. This is fundamentally different from other models in the literature in which nominal

[15] This is shown in the proof to proposition 7.

rigidities only arise as a consequence of some real friction such as menu costs.[16] A compelling theory of equilibrium selection in repeated games does not exist. It is therefore hard to give a forceful theoretical argument for any particular implicit contract. However, the empirical ubiquity of nominal rigidities suggests that firms and consumers may in fact coordinate on implicit contracts that involve price rigidity. A potential reason for this is that such rules may be easier for consumer to understand and verify than fully state-contingent rules. In the context of explicit contracts, costs of writing complicated contracts are often cited as a reason why observed contracts are extremely incomplete. Perhaps it is similarly "more costly" to coordinate on and enforce a complicated state-contingent implicit contract than simple fixed price rules.[17]

4 Asymmetric Information

Many components of a typical firm's marginal costs and demand are either unobservable or very costly for a consumer to observe. In section 3, we showed that in a complete-information setting the most favorable sustainable price path from the firm's perspective is one in which the price is a function of the firm's marginal costs and its demand. If marginal costs and demand are unobservable to the consumers, such price paths are unsustainable since there is no way for consumers to verify whether the firm deviates from them or not. This observation raises the question: What is most favorable sustainable price path from the firm's perspective when it has private information about its marginal costs and demand?

It turns out that this question is formally related to the problem studied by Athey et al. (2004). They study the time-inconsistency problem of a central bank that has private information about the state of the economy. Using methods developed by Abreu et al. (1990), they are able to show that under relatively mild restrictions this type of problem has a surprisingly simple solution.

[16]The presence of nominal price rigidity in the set of equilibrium outcomes of our model has an important parallel in the recent literature on wage stickiness. Hall (2005) shows that nominal wage stickiness can also arise as an equilibrium outcome in search models of the labor market. Hall's results follow from the fact that the outcome of the bargain between workers and firms, once they have been matched, is indeterminate in such models.

[17]All the results of this section and section 2 hold not only when $\gamma \geq 0$ but also for $\gamma < 0$. The demand curve—equation (12)—with $\gamma < 0$ may be interpreted as describing consumer demand for goods for which consumer's purchases in the recent past negatively affect their current demand. Many durable goods are examples of such goods. In this case the firm faces a slightly different time-inconsistency problem. It would like to be able to commit not to *lower* its price in the immediate future since expectations of low future prices will lead consumers to delay their purchases. This implies that firms again have an incentive to make repricing costly in order to make it more credible that they will not "take advantage of past customers" by lowering their price.

Proposition 8 states a similarly simple result about the most favorable sustainable price path from the firms perspective when marginal costs and demand are unobservable.[18]

Proposition 8. *Assume that $\hat{S}_t$ and $\hat{\Upsilon}_t$ are unobservable to the consumers but that their probability distributions are known and the probability distribution of $\hat{\Phi}_t = \hat{S}_t + \hat{\Upsilon}_t$ is bounded on the interval $[\underline{\hat{\Phi}}, \bar{\hat{\Phi}}]$ and satisfies a monotone hazard condition. Assume also that $\beta > \underline{\beta}$. The sustainable plan that maximizes the value of the firm at time 0 in this case has the firm do one of two things from $t = 1$ on:*

I. If $\gamma > -\underline{\hat{\Phi}}$, the firm sets a constant price $\hat{p}_t(z) = E\hat{p}^c(\hat{\Phi}_t, z) = 0$.

II. If $\gamma < -\underline{\hat{\Phi}}$, the firm sets

$$\hat{p}_t(z) = \begin{cases} \hat{p}^m(\hat{\Phi}_t; z) \text{ if } \hat{\Phi}_t \in [\underline{\hat{\Phi}}, \hat{\Phi}^*] \\ \hat{p}^m(\hat{\Phi}^*; z) \text{ if } \hat{\Phi}_t \in [\hat{\Phi}^*, \bar{\hat{\Phi}}]. \end{cases} \tag{21}$$

If the firm deviates from this, it sets $p_t(z) = p_t^m(z)$ forever after.

Proof: See Appendix A. ∎

This firm-preferred price path takes the form of an implicit contract that limits the firms discretion by setting a "price cap" above which the firm can not set its price. When $\hat{\Phi}_t$ is relatively low, the firm acts with discretion—i.e. sets $\hat{p}_t(z) = \hat{p}_t^m(z)$. However, when $\hat{\Phi}_t > \hat{\Phi}^*$, the firm sets its price equal to the price cap (which is equal to the discretionary price for $\hat{\Phi}_t = \hat{\Phi}^*$). Athey et al. (2004) refer to this as bounded discretion. The level of the price cap depends on the severity of the time-inconsistency problem, which in turn depends on the strength of the habit that consumers develop in the firm's good. In other words, the cutoff $\hat{\Phi}^*$ is decreasing in γ. Thus, the firm's desire to limit its discretion increases with the severity of the time-inconsistency problem.[19]

Proposition 8 shows that the firm's optimal pricing policy when it has private information about its desired price is one in which its price is upward-rigid at a price cap. Below this cap

[18] For simplicity, we model the unobservability of demand by assuming that $\hat{\Upsilon}_t$ is unobservable to the consumers. One way to motivate the unobservability of $\hat{\Upsilon}_t$ is to suppose that the population is made up of two groups: Group 1 has no habit and a low $\hat{\Upsilon}$. Group 2 has habits and a higher $\hat{\Upsilon}$. Unobservable variation in the relative size of these two groups then causes unobservable variation in the market $\hat{\Upsilon}_t$. A technical appendix, available upon request, contains a detailed derivation of this extention of our baseline model.

[19] As with the earlier sections, the results of this section may also be extended to the case of $\gamma < 0$. In this case the optimal pricing policy from the firm's perspective is a "price floor" rather than a price cap. This is because in the $\gamma < 0$ case the firm's time-inconsistency problem leads firms to set too low prices rather than too high prices (see footnote 17).

the firm's price is flexible. Even a casual look at time series of goods prices reveals that exactly these features—a rigid price cap and frequent and flexible sales—appear to be salient features of goods prices. In section 5, we provide formal empirical evidence that shows that these empirical predictions of our model are indeed prominent features of retail prices.

The combination of a rigid upper bound and much more flexibility below the upper bound is something that other models in the literature have not been able to produce. In the macroeconomics literature, various frictions have been employed to generate price rigidity. The frequency of sales observed in the data is hard to reconcile with these frictions. In the industrial organization literature, a large literature has studied temporary sales. However, the models in this literature don't provide a convincing rationale for a rigid regular price that truncates the price distribution from above. In Varian's (1980) model of sales, random variation in prices arises from the presence of uninformed consumers. However, this model generates an equilibrium price distribution with no mass points. Sobel (1984) and Pesendorfer (2002) present alternative models of sales in which sales arise when low-valuation, low discount-factor consumers build up in the market. These models also fail to generate a convincing explanation for the sticky upper bound on prices, since a rigid "regular price" only exists if the discount factor of low valuation consumers is exactly zero and the distribution of consumer valuations is bounded from above. Finally, Aguirregabiria (1999) presents a motive for sales based on store inventories. However, this model also generates continuous variation in prices.

We do not explicitly model the rationale for temporary sales. Rather, we simply introduce exogenous time-variation in the price elasticity of demand of the representative consumer in our model, Υ_t. This variable is meant to capture features of the demand structure faced by the firm that are not explicitly modeled, including the demand-side rationales for temporary sales discussed above.

We have derived results for the simple case in which the consumer cannot observe any of the variables that the firm would like to make its price depend on. Our results can, however, be extended to a setting in which the consumer observes some such variables but not others. In this case, the variables that the consumer observes are state variables and the price cap would be a function of these variables.

5 Empirical Evidence

In this section we present several different types of empirical evidence supporting our model of price rigidity. We first present two kinds of new evidence on price rigidity: evidence from retail price data and evidence from company announcements. We then discuss three sets of existing evidence supporting our model.

5.1 New Evidence from Retail Prices

In section 4, we show that our model has the following empirical prediction: Goods prices should spend a significant portion of their time at a rigid upper bound. Below this upper bound, they should exhibit much more flexibility. In tables 1 and 2, we use weekly price data from the Dominick's Finer Foods (DFF) dataset provided by the University of Chicago Graduate School of Business to show that these predictions are indeed borne out by data on retail goods prices.[20] More precisely, the results presented in tables 1 and 2 along with the fact that we very rarely observe "reverse-sales"—i.e., brief periods during which the price of a good rises above its regular price and then returns back to the regular price—show that: i) The regular price of a good remains fixed for long periods of time, but during this time the good frequently goes on sale for brief periods; ii) Regular prices are a sticky upper bound for the price of a good; iii) Prices generally return to their old regular price after sales; and iv) Sale prices are more than 8 times more flexible than regular prices. For robustness, the statistics in tables 1 and 2 are presented separately for each of 26 categories of goods. Hosken and Reiffen (2004) document similar qualitative results to (i) and (ii) for a panel of monthly data from 30 U.S. metropolitan areas.

The concept of a "regular price" is familiar in the literature on retail prices (see, e.g., Chevalier et al., 2003). One way to identify deviations from the regular price is to use data on the timing of promotions. The labeling of promotions in the Dominick's dataset is, however, somewhat undependable.[21] Moreover, what we typically view as a sale—i.e., a short-term decrease in prices relative

[20] DFF is the second-largest supermarket chain in the Chicago metropolitan area with approximately 100 stores and a 25% market share. DFF provided the University of Chicago Graduate School of Business (GSB) with weekly store-level scanner data, available at http://gsbwww.uchicago.edu/kilts/research/db/dominicks/. See Chevalier et al. (2003) for a more detailed description of this data set. We use data from store number 126 since the data from this store has the least missing data points.

[21] According the University of Chicago GSB website describing the data, "if the variable is set it indicates a promotion, if it is not set, there might still be a promotion that week".

to a recurrent upper bound—is more closely related to the time series behavior of prices than the presence of a promotion. We therefore identify sales directly from observations on prices as periods when the price drops for a short period and then returns to either a previously occurring regular price or to a new regular price that reoccurs soon after.[22] The "sales filter" used to identify sales is described in detail in appendix C. To give the reader a feel for this procedure, figures 1-3 show the original and "regular price" series for three popular items (Nabisco Premium Saltines 16oz, Diet Coke 2L and Kraft Singles 16oz, respectively). The figures show that the regular price series generated by this procedure corresponds well with our intuition about how to define a sale. The price series have infrequent adjustments in regular prices and frequent sales. When no recurring regular price can be identified from the data, the sales filter simply sets the regular price equal to the observed price. Thus, a continuously adjusting price series would have the regular price always equal to the actual price—i.e., no sales—with a regular price change in every period.[23]

Column 1 of table 1 presents the fraction of weeks in which the price of the good was equal to the regular price. One minus this number is the fraction of time the good was on sale. According to this measure, sales occur about 13% of the time. Column 1 of table 2 presents the frequency of price change of the regular price. The regular price often remains fixed for significant periods of time—the frequency of price adjustment of regular prices is 6.1% or less in more than half of the categories.

Column 2 of table 1 reports the fraction of sales that return to the original regular price. For most products the price of the product returns to the original regular price over 90 percent of the time following a sale.[24] Given the high frequency of sales, this statistic implies that the opportunity to adjust the regular price following a sale is often forgone. This is hard to reconcile with the standard menu cost model of price rigidity in which a firm should always readjust the

[22]This procedure has the advantage over the procedure suggested in Hosken and Reiffen (2004)—of defining sales as percentage deviations from the modal price—that it can accommodate variation in the regular price within a year and allows for sales that last more than one period.

[23]A very irregular pattern of sales, such as the one near the end of figure 2, is not identified by the sales filter. The sales filter is, thus, somewhat conservative in assigning variation in prices to sales rather than the regular price. This tendency biases us away from finding a high frequency of sales, and a low frequency of price adjustment of regular prices—two of the key findings discussed in this section. Another comforting fact about our procedure is that the qualitative findings (i)- (iv) are not at all sensitive to the exact parameters used in the sales filter. Furthermore, Hosken and Reiffen (2004) document very similar qualitative results for (i) and (ii) using an entirely different data set and a different procedure for identifying sales.

[24]This is not by construction. Our sales filter allows for sales that do not return to the original price following the sale, as we discuss in appendix C.

regular price when a sale ends.

Column 4 of table 2 reports the number of unique sale values as a fraction of the total number of weeks spent on sale. This statistic would equal 1 if there were a unique sale price in every sale period and would approach zero if only one sale price was ever visited. Column 3 of table 2 reports an analogous statistic for regular prices. Sale prices are considerably more variable than regular prices. The median value of this fraction across categories for sale prices is 43%. In contrast, the same statistic for regular prices is 4.5%, about 10 time smaller.[25] The data are not, therefore, consistent with the idea that the price always returns to a particular sale price when the product goes on sale.

A slightly different way of analyzing the relative rigidity of sale prices is to look at the tendency of prices to adjust *while* the product is on sale versus at other times. Recall that our procedure for identifying sales allows for sales that last for more than one week. Multi-week sales account for somewhat less than half of sales in most categories. Columns 1 and 2 of table 2 compare the frequency of price adjustment for regular prices versus sale prices during multi-week sales, not including the price changes at the start and end of the sale. The frequency of price adjustment during sales is about 8 times as high as the frequency of adjustment of the regular price.[26] Existing menu cost models of price rigidity do not provide any reason why the price of a good should be more flexible when it is on sale. As we showed in section 4, this pricing pattern is however a natural implication of our model.[27]

From the perspective of the customer markets model presented in this paper, this pattern of pricing reflects the fact that the firm chooses to commit to a sticky price cap. The results in section 4 show that committing to a sticky price cap, but allowing sale prices to fluctuate, is preferable from the perspective of the firm to fixing its price for multiple periods or other types of pricing rules that do not depend on costs.

[25] An even higher fraction of sale prices are unique if the prices are defined in terms of percent off the regular price, or an absolute amount off the regular price.

[26] Levy et al. (2005) find an even greater difference in the flexibility of regular prices and sales prices in the DFF dataset. Using a different algorithm to identify sales they estimate that sales prices are 64 times more likely to change than regular prices.

[27] Again, these empirical facts do not arise from the particular approach used to identify sales, since our algorithm does not in any way affect the dynamics of prices during a sale.

5.2 New Evidence from Company Announcements

If barriers to price adjustment are a hindrance to firms, why do firms self-impose restrictions to their future prices? On May 23 2002, Marvel CEO Bill Jemas began a pricing conference with the statement: "Read my lips, we will not raise prices." On Oct 9 2000, Revlon Inc. announced as part of its new terms of trade a "commitment not to raise prices for its retail partners in 2001". On Dec 1 2004, Apple Computer "flatly denied a report that...[it] was planning to raise prices for songs bought on the popular iTunes online music store...'These rumors aren't true,' said Apple spokeswoman Natalie Sequerira. 'We have multiyear agreements with the labels and our prices remain 99c a track.' " On Aug 24 2004, B. Muthuraman, managing director of Tata Steel said, "We will not increase prices for both our direct customers as well as our retail customers til March 2005." The web-hosting company Tech Trade Internet Services states on its website "Price Freeze Guarantee. Same Price. Forever."

These examples were collected from news articles and company webpages on the internet. A number of similar examples from the steel industry, power and electricity, petroleum and gas, telephone services, internet service providers and other industrial and consumer goods industries are presented in table 3.

In some cases, an explanation is provided. The large fence manufacturer Sarel states:

> Sarel ... has had no price increases for more than five years and no price changes are expected in the forseeable future. ... When [customers have] made their choice, the exceptional stability of our prices means that they know not only that they're getting superb value for their money today, but also that they will continue to do so in the future.

A small photofinishing company "Color Express" states:

> Once we publish our price list, our track record proves that we commit to those prices: it's not uncommon to maintain prices for one or two years barring significant increases in the paper industry. Take a look at other published prices, and you will find revisions sometimes as frequently as every 3-6 months. Even if the competitions prices are "slashed", doesn't it make you wonder?

Though far from conclusive, these anecdotes provide concrete examples of firms "committing to a sticky price", sometimes for the stated purpose of affecting consumers' future price expectations.[28]

5.3 Survey Evidence on the Reasons for Price Rigidity

An important source of evidence on price rigidity and the reasons for price rigidity is surveys. An influential survey on price rigidity was conducted by Blinder et al. (1998) for U.S. manufacturing firms. Blinder et al. interviewed managers at about 200 firms and asked them how often they changed their prices and why they didn't change them more often. This type of study has since been conduced in a host of other countries using similar methodology and in some cases with a much larger sample size than Blinder et al.'s original survey (see footnote 3).

The results of these surveys are strikingly similar across countries. A major conclusion is that the primary reason why firms seem to be reluctant to change their prices is because their customers don't like price variability rather than because such variability is costly for the firm independent of customer reactions. The importance of customer-based explanations for price rigidity is reflected in robustly high scores for the implicit contracts explanation for price rigidity and the robustly low scores for the menu cost and firm information cost explanations. Follow up questions in Blinder's survey also strongly suggest that the main concern that firms have with changing their prices is antagonizing customers.

5.4 Are Prices More Rigid in Customer Markets?

If consumer lock-in is an important source of price rigidity, we should observe stickier prices in firms that have more repeat customers. The existing survey and experimental evidence on the relationship between "customer markets" and price rigidity, though limited, suggests that this is indeed the case.

In an experiment on price-setting in customer markets, Cason and Friedman (2002) show that higher search costs lead customers to remain with sellers for longer periods. Sellers respond to this increase in loyalty with significantly more rigid prices. Renner and Tyran (2004) study a setting in which buyers are uncertain about the quality of competing products. They show that the price rigidity is more pronounced in a customer market than a market without repeat customers

[28] Another potential explanation for firms pre-announcing their prices is collusion.

following an increase in costs, and that price rigidity is more pronounced if the increase in costs is unobservable than if it is public information. The latter finding lines up well with our results in section 4.

Survey evidence also suggests that the link between customer markets and price rigidity may be important. In a survey of British firms, Hall et al. (1997) find that companies with over 75% of their customer relationships lasting for longer than five years rated fixed-price contracts as more important than firms with a smaller fraction of long-term customers. Small and Yates (1999) find that customer turnover seems to have a significant effect on the responsiveness of prices to changes in cost, but not to changes in demand. Carlton (1986) finds no evidence for a relationship between price rigidity and the importance of long-term contracts in a cross-industry study of the Stigler-Kindahl data set. However, the number of observations in Carlton's study is small and the result may be confounded by other differences across industries.

5.5 Are Prices More Rigid for Existing Customers?

Another empirical implication of the model presented in sections 3-4 (more precisely, a slight extension of that model) is that if it is possible to price discriminate between new and old customers, prices for new customers should not exhibit the same degree of rigidity as prices for existing customers. This is because the firm has not yet made an implicit contract with the new customer. It is therefore free to make use of all current information when it sets the initial price for the new customer while only information available to the consumer can be used to justify changes in the price the firm charges existing customers.

The practice of maintaining fixed prices for existing customers when prices for new customers are changed is referred to as "grandfathering". This practice has been studied in the economics literature for housing rents and long-distance phone services. Genesove (2003) shows that the rent on an apartment is about twice as likely to change when a new tenant moves in as when an old tenant signs a new lease. Epling (2002) shows that long distance telephone companies often maintain fixed prices for existing customers when they change prices for new customers.

The results of Carlton (1986) also suggest more rigidity to existing customers. Carlton uses the Stigler-Kindahl data set to show that prices for a particular buyer are rigid for long periods of time and contrasts this with the results of Stigler and Kindahl (1970). Stigler and Kindahl show that price indexes of average transaction prices are quite flexible. Together these two facts strongly suggest that prices for existing customers are more rigid than prices for new customers for the Stigler-Kindahl data.

6 Concluding Remarks

In this paper, we show that time non-separabilities in consumer demand imply that firms face a time-inconsistency problem when they are choosing prices. They would like to promise low prices in the future. But when the future arrives they have an incentive to take advantage of consumers' habits and price gouge. In this model, price rigidity arises as an equilibrium outcome. Moreover, firms may benefit from menu costs since they help firms commit not to price gouge. The firms' optimal policy is to commit to a state-contingent pricing policy. However, there are various reasons why this pricing rule may not be selected in the market. One reason is that the firms' marginal costs and demand may not be observable. Another reason is that it may be costly to write complicated contracts or commit to a complicated pricing rule.

If firms have private information about their desired prices, the optimal pricing policy is to commit to a price cap. Our model therefore implies that prices should spend a significant portion of their time at a rigid upper bound. Below this upper bound, they should be much more flexible. As we show in section 5, the behavior of retail prices bears a striking resemblance to this price cap policy. In contrast, the combination of a rigid regular price and frequent sales is difficult to explain within standard models of menu costs. Our model also explains why firms fear adverse reactions to price changes, why sales prices are more flexible than regular prices, why firms make explicit promises not to change prices and why price are more rigid to repeat customers than to one-time customers.

A Proofs of Propositions and Lemma's

A.1 Proposition 1

Proof: The Lagrangian for the firm's problem is

$$\begin{aligned}\mathcal{L}(z) = & (p_1(z) - W)c_1(z) + M(p_2(z) - W)c_2(z) \\ & -\mu_1(c_1(z) - C_1 P_1^\theta (p_1(z) + \gamma M p_2(z))^{-\theta}) \\ & -M\mu_2(c_2(z) - \gamma c_1(z) - C_2 P_2^\theta p_2(z)^{-\theta})\end{aligned}$$

Differentiating this expression with respect to $p_1(z)$, $p_2(z)$, $c_1(z)$, $c_2(z)$ and setting the resulting expressions equal to zero yields

$$c_1(z) - \theta\mu_1 C_1 P_1^\theta (p_1(z) + \gamma M p_2(z))^{-\theta-1} = 0,$$

$$c_2(z) - \gamma\theta\mu_1 C_1 P_1^\theta (p_1(z) + \gamma M p_2(z))^{-\theta-1} - \theta\mu_2 C_2 P_2^\theta p_2(z)^{-\theta-1} = 0,$$

$$p_1(z) - W = \mu_1 - \gamma M \mu_2,$$

$$p_2(z) - W = \mu_2,$$

respectively. Manipulation of these equations and the consumers' demand curves—equations (6)-(7)—yields the expressions for $p_1(z)$ and $p_2(z)$ given in the proposition. ■

A.2 Proposition 2

Proof: We begin by solving the firm's problem at time 1 conditional on $p_2(z)$. Differentiating the expression for $\Pi_1(z)$ given in equation (5) with respect to $p_1(z)$ and setting the resulting expression equal to zero yields (after a bit of manipulation)

$$p_1(z) + \gamma M p_2(z) = \frac{\theta}{\theta - 1}(1 + \gamma M)W. \tag{22}$$

This implies that

$$c_1^d(z) = c_1^c(z) = C_1 P_1^\theta \left(\frac{\theta}{\theta - 1}\right)^{-\theta} (1 + \gamma M)^{-\theta} W^{-\theta}.$$

Next, we solve the firm's problem at time 2 conditional on $c_1(z)$. Differentiating the expression for $\Pi_2(z)$ given in equation (9) with respect to $p_2(z)$ yields

$$\frac{\partial \Pi_2(z)}{\partial p_2(z)} = \gamma c_1(z) - (\theta - 1)C_2 P_2^\theta p_2(z)^{-\theta} + \theta C_2 P_2^\theta W p_2(z)^{-\theta-1}.$$

For the firm's problem at time 2 to have a solution, there must exist a value of $p_2(z)$ such that $\partial\Pi_2(z)/\partial p_2(z) = 0$. Notice that the last two terms in the expression for $\partial\Pi_2(z)/\partial p_2(z)$ are minimized when

$$p_2(z) = \frac{\theta+1}{\theta-1}W.$$

This implies that the firms problem has a solution if

$$\gamma c_1(z) \leq (\theta-1)C_2P_2^\theta\left(\frac{\theta+1}{\theta-1}\right)^{-\theta}W^{-\theta} + \theta C_2P_2^\theta\left(\frac{\theta+1}{\theta-1}\right)^{-\theta-1}W^{-\theta}.$$

Using the expression for $c_1(z)$ derived above, we can rewrite this condition as

$$\frac{\gamma}{(1+\gamma M)^\theta}\frac{C_1P_1^\theta}{C_2P_2^\theta} < \left(\frac{\theta}{\theta+1}\right)^\theta\left(\theta-1+\frac{\theta}{\theta-1}\right). \tag{23}$$

This condition is satisfied if $\gamma \leq C_2P_2^\theta/C_1P_2^\theta$. Notice that if $\gamma = 0$, $\partial\Pi_2(z)/\partial p_2(z) = 0$ implies $p_2(z) = p_2^c(z) = \theta W/(\theta-1)$. Notice also that the sum of the last two terms in the expression for $\partial\Pi_2(z)/\partial p_2(z)$ are decreasing on the interval $[\theta W/(\theta-1), (\theta+1)W/(\theta-1)]$. This implies that for $0 < \gamma \leq 1$ we have that

$$\frac{\theta}{\theta-1}W < p_2^d(z) < \frac{\theta+1}{\theta-1}W.$$

It also implies that $\partial p_2(z)/\partial\gamma > 0$. And together with equation (22) it implies that $p_1^d(z) < p_1^c(z)$. The deviation from CES preferences for $c_2(z) - \gamma c_1(z) \leq c^*$ discussed in footnote 9 rules out solutions in which the $p_2(z) > (\theta+1)W/(\theta-1)$. Notice that since $p_2^d(z) > p_2^c(z) = p_1^c(z) > p_1^d(z)$ for all z we have that $P_2 > P_1$ under discretion. So, $C_2/C_1 < C_2P_2^\theta/C_1P_2^\theta$ implying that condition (23) holds for all $\gamma \leq C_2/C_1$.

The fact that $\Pi^d(z) < \Pi^c(z)$ follows immediately from the fact that $p_1^c(z)$ and $p_2^c(z)$ are the unique solution to the problem of maximizing firm profits subject to the consumers' demand curves.

■

A.3 Proposition 3

Proof: We prove the result by backward induction. First, consider the firm's choice of $p_2(z)$. If $p_1(z) = p_1^c(z)$ and $c_1(z) = c_1^c(z)$, the firm will choose $p_2(z) = p_2^c(z) = p_1^c(z)$ as long as

$$\max_{p_2(z)}(p_2(z)-W)(\gamma c_1^c(z) + C_2P_2^\theta p_2(z)^{-\theta}) - (p_1^c(z)-W)(\gamma c_1^c(z) + C_2P_2^\theta p_1^c(z)^{-\theta}) < \tau. \tag{24}$$

If $c_1(z)$ is sufficiently high, the firm will choose $p_2(z) > p_2^c(z)$. If $c_1(z)$ is sufficiently low, the firm will choose $p_2(z) < p_2^c(z)$.

Next, consider the consumer's choice of $c_1(z)$. If $p_1(z) = p_1^c(z)$ and given the choices of the firm in period 2 described above, $c_1(z) = c_1^c(z)$ is the only price that satisfies the consumers demand curve.

Finally, given the firm's behavior in period 2 and the consumer's behavior in period 1, it is optimal for the firm to set $p_1(z) = p_1^c(z)$ since it can do no better than to attain the commitment outcome.

The cutoff $\underline{\tau}$ is therefore defined by

$$\underline{\tau} = \max_{p_2(z)} (p_2(z) - W)(\gamma c_1^c(z) + C_2 P_2^\theta p_2(z)^{-\theta}) - (p_1^c(z) - W)(\gamma c_1^c(z) + C_2 P_2^\theta p_1^c(z)^{-\theta}).$$

■

A.4 Proposition 4

Proof: The firm seeks to maximize equation (13) subject to equations (12) with $\theta_t = \theta$ and (14). A Lagrangian for this constrained optimization problem is

$$\begin{aligned}\mathcal{L}_0 = E_0 \sum_{t=0}^{\infty} M_{0,t} [&p_t(z)c_t(z) - W_t L_t(z) - S_t(c_t(z) - A_t f(L_t(z))) \\ &-\Psi_t(-p_t(z) + P_t C_t^{\frac{1}{\theta}}(c_t(z) - \gamma c_{t-1}(z))^{-\frac{1}{\theta}} - \gamma M_{t,t+1}(P_{t+1} C_{t+1}^{\frac{1}{\theta}}(c_{t+1}(z) - \gamma c_t(z))^{-\frac{1}{\theta}})],\end{aligned}$$

where S_t and Ψ_t denote Lagrange multipliers. The first order conditions of this problem are

$$S_t = \frac{W_t}{A_t f'(L_t(z))},$$

$$\begin{aligned}\frac{1}{\theta}(\Psi_t - \gamma\Psi_{t-1}) P_t C_t^{\frac{1}{\theta}} (c_t(z) - \gamma c_{t-1}(z))^{-\frac{1+\theta}{\theta}} &= -p_t(z) + S_t \\ &+ \frac{\gamma}{\theta} E_t[M_{t,t+1}(\Psi_{t+1} - \gamma\Psi_t) P_{t+1} C_{t+1}^{\frac{1}{\theta}} (c_{t+1}(z) - \gamma c_t(z))^{-\frac{1+\theta}{\theta}}],\end{aligned}$$

for $t \geq 0$, $\Psi_t = -c_t(z)$ for $t \geq 1$, $\Psi_0 = 0$ and a transversality condition. Manipulation of these equations and equation (12) yields

$$p_t(z) = \frac{\theta}{\theta - 1} S_t$$

for $t \geq 1$. ■

A.5 Lemma 1

Proof: We can rearrange equation (17) so that it says that

$$\frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z)-\frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_{t-1}(z)-\frac{\gamma\beta}{1-\gamma-\gamma\beta}E_t\hat{c}_{t+1}(z)=-\theta\hat{p}_t(z)-\frac{1}{2}\frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z)^2$$
$$+\frac{1}{2}\frac{1+\theta}{\theta(1-\gamma)(1-\gamma-\gamma\beta)}\hat{c}_t(z)^2-\frac{\theta-1}{1-\gamma-\gamma\beta}\hat{c}_t(z)\hat{\Upsilon}_t-\frac{1}{2}\frac{\theta}{1-\gamma-\gamma\beta}\hat{p}_t(z)^2$$
$$-\frac{1}{1-\gamma-\gamma\beta}\left(\theta\hat{P}_t+\hat{C}_t-\hat{P}_t\hat{c}_t(z)-\frac{1}{\theta}\hat{C}_t\hat{c}_t(z)\right)+\text{ s.o.ex.terms}+\mathcal{O}(||\xi,\gamma||^3).$$

Now notice that equation (16) may be written

$$E_0\sum_{t=0}^{\infty}p(z)c(z)\beta^t\left[\frac{1}{\theta}\left(\frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z)-\frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_{t-1}(z)-\frac{\gamma\beta}{1-\gamma-\gamma\beta}\hat{c}_{t+1}(z)\right)\right.$$
$$+\left(\hat{p}_t(z)+\frac{1}{2}\hat{p}_t(z)^2\right)+\frac{1}{\theta}\frac{1}{2}\hat{c}_t(z)^2+\hat{p}_t(z)\hat{c}_t(z)-\frac{\theta-1}{\theta}\hat{S}_t\hat{c}_t(z)$$
$$\left.+\hat{p}_t(z)\hat{M}_{0,t}+\frac{1}{\theta}\hat{c}_t(z)\hat{M}_{0,t}\right]-p(z)c(z)\frac{1}{\theta}\frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_0(z)+\text{ ex. terms}+\mathcal{O}(||\xi,\gamma||^3).$$

Substituting consumer demand into this expression now yields

$$E_0\sum_{t=0}^{\infty}p(z)c(z)\beta^t\left[\frac{1}{\theta}\left(-\frac{1}{2}\frac{1}{1-\gamma-\gamma\beta}\left(\hat{c}_t(z)^2-\frac{1+\theta}{\theta(1-\gamma)}\hat{c}_t(z)^2+2(\theta-1)\hat{c}_t(z)\hat{\Upsilon}_t+\theta\hat{p}_t(z)^2\right.\right.\right.$$
$$\left.\left.-2\hat{P}_t\hat{c}_t(z)-2\frac{1}{\theta}\hat{C}_t\hat{c}_t(z)\right)\right)+\frac{1}{2}\hat{p}_t(z)^2+\frac{1}{\theta}\frac{1}{2}\hat{c}_t(z)^2+\hat{p}_t(z)\hat{c}_t(z)-\frac{\theta-1}{\theta}\hat{S}_t\hat{c}_t(z)$$
$$\left.+\hat{p}_t(z)\hat{M}_{0,t}+\frac{1}{\theta}\hat{c}_t(z)\hat{M}_{0,t}\right]-p(z)c(z)\frac{1}{\theta}\frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_0(z)+\text{ ex. terms}+\mathcal{O}(||\xi,\gamma||^3).$$

If we now multiply this expression by $(1-\gamma)(1-\gamma-\gamma\beta)$, use consumer demand to substitute for $\hat{c}_t(z)$ and simplify, we get that

$$E_0\sum_{t=0}^{\infty}p(z)c(z)\beta^t\left[\frac{1-\theta}{2}\hat{p}_t(z)^2+(\theta-1)\hat{\Upsilon}_t\hat{p}_t(z)+(\theta-1)\hat{S}_t\hat{p}_t(z)\right]+p(z)c(z)\gamma\hat{p}_0(z)$$
$$+\text{ex. terms}+\mathcal{O}(||\xi,\gamma||^3). \qquad (25)$$

Setting the derivative of this with respect to $\hat{p}_t(z)$ for $tgeq1$ equal to zero shows that the firm's optimal pricing policy under full commitment to a state-contingent rule for $t\geq 1$ is

$$\hat{p}_t(z)=\hat{S}_t+\hat{\Upsilon}_t$$

up to an error of order $\mathcal{O}(||\xi,\gamma||^2)$. ■

A.6 Proposition 5

Proof: A derivation analogous to the derivation of expression (25) yields that the objective of the firm at time t can be written as

$$E_t \sum_{j=0}^{\infty} p(z)c(z)\beta^j \left[\frac{1-\theta}{2} \hat{p}_{t+j}(z)^2 + (\theta - 1)\hat{\Upsilon}_{t+j}\hat{p}_{t+j}(z) + (\theta - 1)\hat{S}_{t+j}\hat{p}_{t+j}(z) \right] + p(z)c(z)\gamma\hat{p}_t(z)$$
$$+\text{ex. terms} + \mathcal{O}(||\xi,\gamma||^3). \quad (26)$$

The firm maximizes this expression with respect to the current period price $\hat{p}_t(z)$. This yields

$$\hat{p}_t(z) = \frac{\gamma}{\theta - 1} + \hat{S}_t + \hat{\Upsilon}_t, \quad (27)$$

up to an error of order $\mathcal{O}(||\xi,\gamma||^2)$. ■

A.7 Proposition 6

Proof: We must show that the firm does not have a profitable deviation when it is setting $p_t(z) = p_t^c(z)$. The benefit from deviating at this point is a higher price in the current period. Denote this benefit by $\Pi_t^d - \Pi_t^c$. The loss is the change in future profits associated with playing the Markov perfect equilibrium in future periods rather than $p_{t+j}(z) = p_{t+j}^c(z)$. Denote the expected loss in the period after the defiation by $E[\Pi_{+1}^c - \Pi_{+1}^m]$ and the per period loss in subsequent periods by $E[\Pi^c - \Pi^m]$. The firm will refrain from deviating in the current period if $\Pi_t^d - \Pi_t^c < \beta E[\Pi_{+1}^c - \Pi_{+1}^m] + \beta^2 E[\Pi^c - \Pi^m]/(1-\beta)$. This condition will hold for all $\beta > \underline{\beta}_t$ where $\underline{\beta}_t$ is implicitely defined by $\Pi_t^d - \Pi_t^c = \underline{\beta}_t E[\Pi_{+1}^c - \Pi_{+1}^m] + \underline{\beta}_t^2 E[\Pi^c - \Pi^m]/(1-\underline{\beta}_t)$. The firm will never deviate if $\beta > \underline{\beta} = \max \underline{\beta}_t$. It is relatively easy to show that $\underline{\beta}$ is independent of γ. ■

A.8 Proposition 7

Proof: First, we show that the profit maximizing price rule assuming that prices can only be changed in odd numbered periods is given by equation (20). The value of the firm's expected profits from period t on are given by expression (26). The firm maximizes this expression with respect to $\hat{p}_t$ subject to the constraint $\hat{p}_t(z) = \hat{p}_{t+1}(z)$. We can use this constraint to eliminate $\hat{p}_{t+1}(z)$ in expression (26) and rewrite it ignoring terms that are exogenous to the firm's time t

problem. This yields

$$p(z)c(z)\left[\frac{(1-\theta)(1+\beta)}{2}\hat{p}_t(z)^2+(\theta-1)\hat{\Upsilon}_t\hat{p}_t(z)+(\theta-1)\hat{S}_t\hat{p}_t(z)+\gamma\hat{p}_t(z)\right]$$
$$+\text{ex. terms}+\mathcal{O}(||\xi,\gamma||^3). \quad (28)$$

Maximizing this with respect to $\hat{p}_t(z)$ yields equation (20).

Next, we show that the value expected profits in future periods from adhering to the price path stated in the proposition is greater than from playing the Markov perfect equilibrium. The value of the expected future profits is equal to

$$E_t\sum_{j=1}^{\infty}p(z)c(z)\beta^j\left[\frac{1-\theta}{2}\hat{p}_{t+j}(z)^2+(\theta-1)(\hat{S}_{t+j}+\hat{\Upsilon}_{t+j})\hat{p}_{t+j}(z)\right]+\text{ex. terms}+\mathcal{O}(||\xi,\gamma||^3).$$

Using equation (18) we can derive that, ignoring exogenous terms and terms of higher than second order, the value of the expected profits of a firm if it plays the Markov perfect equilibrium in all future periods is

$$E_t\Pi^m_{t+1}=p(z)c(z)\frac{\beta}{1-\beta}\frac{\theta-1}{2}\left[-\left(\frac{\gamma}{\theta-1}\right)^2+\text{var}(\hat{S}_t+\hat{\Upsilon}_t)\right].$$

Similarly, using equation (20) we can derive that the value of the expected profits of a firm that prices according the the rule in the proposition is larger than or equal to

$$\begin{aligned}\min_{\hat{S}_t+\hat{\Upsilon}_t}E_t\Pi^F_{t+1} &= \min_{\hat{S}_t+\hat{\Upsilon}_t}\left[p(z)c(z)\beta\frac{\theta-1}{2}\left[-\left(\frac{\gamma}{(\theta-1)(1+\beta)}\right)^2+\frac{1+2\beta}{(1+\beta)^2}(\hat{S}_t+\hat{\Upsilon}_t)^2\right]\right.\\ &\quad\left.+p(z)c(z)\frac{\beta^2}{1-\beta}\frac{\theta-1}{2}\left[-\left(\frac{\gamma}{(\theta-1)(1+\beta)}\right)^2+\frac{1+2\beta}{(1+\beta)^2}\text{var}(\hat{S}_t+\hat{\Upsilon}_t)\right]\right]\\ &= p(z)c(z)\frac{\beta}{1-\beta}\frac{\theta-1}{2}\left[-\left(\frac{\gamma}{(\theta-1)(1+\beta)}\right)^2+\frac{\beta(1+2\beta)}{(1+\beta)^2}\text{var}(\hat{S}_t+\hat{\Upsilon}_t)\right]\end{aligned}$$

Comparing these expressions we get that $\min_{\hat{S}_t+\hat{\Upsilon}_t}E_t\Pi^F_{t+1}>E_t\Pi^m_{t+1}$ if

$$\gamma^2>(\theta-1)^2\frac{1+\beta-\beta^2}{2\beta+\beta^2}\text{var}(\hat{S}_t+\hat{\Upsilon}_t).$$

Given this condition an argument analogous to the one given in the proof of Proposition 6 implies that the firm does not have a profitable deviation while it is setting its price according to equation (20) as long as $\beta>\underline{\beta}$. ■

A.9 Proposition 8

We must show that the portion of the price path described in the proposition that is played in equilibrium is the best feasible price path from the firm's perspective. Once we have shown this, an argument analogous to the proof of Proposition 6 implies that the firm does not have a profitable deviation from this price path.

We begin by deriving the function in our model that correponds to $R(x_t, \mu_t, \theta_t)$ in Athey et al. (2004). In order to do this, it is useful to view the consumer's problem slightly differently than we have in the rest of the paper. Given the consumer's demand curve—equation (17)—one can view the decision the consumer makes at each point in time as a decision about what he expects prices to be in the next period. To see this, notice that we can rewrite equation (17) as

$$\begin{aligned}-\theta\hat{p}_t(z) = {} & \frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z) - \frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_{t-1}(z) - \frac{\gamma\beta}{1-\gamma-\gamma\beta}E_t\hat{c}_{t+1}(z) + \frac{1}{2}\frac{\theta}{1-\gamma-\gamma\beta}\hat{p}_t(z)^2 \\ & + \frac{1}{2}\frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z)^2 - \frac{1}{2}\frac{1+\theta}{\theta(1-\gamma)(1-\gamma-\gamma\beta)}\hat{c}_t(z)^2 - \theta\hat{P}_t - \hat{C}_t \\ & + \frac{1}{(1-\gamma-\gamma\beta)}\left(\hat{P}_t + \frac{1}{\theta}\hat{C}_t + (\theta-1)\hat{\Upsilon}_t\right)\hat{c}_t(z) + \text{ s.o.ex.terms} + \mathcal{O}(||\xi,\gamma||^3).\end{aligned}$$

Notice furthermore that

$$\hat{c}_t(z) = -\theta\hat{p}_t(z) + \theta\hat{P}_t + \hat{C}_t + \mathcal{O}(||\xi,\gamma||^2). \tag{29}$$

Using this fact, we can rewrite the consumer's demand curve as

$$\begin{aligned}-\theta\hat{p}_t(z) = {} & \frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z) - \frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_{t-1}(z) + \frac{\gamma\beta\theta}{1-\gamma-\gamma\beta}E_t\hat{p}_{t+1}(z) + \frac{1}{2}\frac{\theta}{1-\gamma-\gamma\beta}\hat{p}_t(z)^2 \\ & + \frac{1}{2}\frac{\theta^2}{1-\gamma-\gamma\beta}(\hat{p}_t(z)^2 - \hat{P}_t\hat{p}_t(z) - \frac{1}{\theta}\hat{C}_t\hat{p}_t(z)) - \frac{1}{2}\frac{(1+\theta)\theta}{(1-\gamma)(1-\gamma-\gamma\beta)}(\hat{p}_t(z)^2 - \hat{P}_t\hat{p}_t(z) - \frac{1}{\theta}\hat{C}_t\hat{p}_t(z)) \\ & - \theta\hat{P}_t - \hat{C}_t - \frac{\theta}{(1-\gamma-\gamma\beta)}\left(\hat{P}_t + \frac{1}{\theta}\hat{C}_t + (\theta-1)\hat{\Upsilon}_t\right)\hat{p}_t(z) + \text{ s.o.ex.terms} + \mathcal{O}(||\xi,\gamma||^3).\end{aligned}$$

Notice that once the consumer has chosen what to expect about the firm's price in period $t+1$, this equation determines his demand. One can therefore view the consumer's decision at each point given the form of the demand curve as a choice about what to expect about the firm's price in the next period. In equilibrium, the consumer will have rational expectations. We have used this fact by writing the consumer's expectation as $E_t\hat{p}_{t+1}$. However, more generally, we can denote the consumer's expectation about $\hat{p}_t$ at time $t-1$ as x_t. Using this notation, the consumer's demand curve becomes

$$-\theta\hat{p}_t(z) = \frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z) - \frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_{t-1}(z) + \frac{\gamma\beta\theta}{1-\gamma-\gamma\beta}x_{t+1} + \frac{1}{2}\frac{\theta}{1-\gamma-\gamma\beta}\hat{p}_t(z)^2$$
$$+\frac{1}{2}\frac{\theta^2}{1-\gamma-\gamma\beta}(\hat{p}_t(z)^2 - \hat{P}_t\hat{p}_t(z) - \frac{1}{\theta}\hat{C}_t\hat{p}_t(z)) - \frac{1}{2}\frac{(1+\theta)\theta}{(1-\gamma)(1-\gamma-\gamma\beta)}(\hat{p}_t(z)^2 - \hat{P}_t\hat{p}_t(z) - \frac{1}{\theta}\hat{C}_t\hat{p}_t(z))$$
$$-\theta\hat{P}_t - \hat{C}_t - \frac{\theta}{(1-\gamma-\gamma\beta)}\left(\hat{P}_t + \frac{1}{\theta}\hat{C}_t + (\theta-1)\hat{\Upsilon}_t\right)\hat{p}_t(z) + \text{ s.o.ex.terms} + \mathcal{O}(||\xi,\gamma||^3). \quad (30)$$

Next, notice that the second order approximation of the value of the firm—equation (16)—may be written

$$E_0\sum_{t=0}^{\infty} p(z)c(z)\beta^t \left[\hat{p}_t(z) + \frac{1}{\theta}\left(\frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z) - \frac{\gamma}{1-\gamma-\gamma\beta}\hat{c}_{t-1}(z)\right) - \frac{\gamma}{\theta}\frac{1}{1-\gamma-\gamma\beta}\hat{c}_t(z)\right.$$
$$\left.+\frac{1}{2}\hat{p}_t(z)^2 + \frac{1}{\theta}\frac{1}{2}\hat{c}_t(z)^2 + \hat{p}_t(z)\hat{c}_t(z) - \frac{\theta-1}{\theta}\hat{S}_t\hat{c}_t(z) + \hat{p}_t(z)\hat{M}_{0,t} + \frac{1}{\theta}\hat{c}_t(z)\hat{M}_{0,t}\right]$$
$$+\text{ex. terms} + \mathcal{O}(||\xi||^3)$$

Using equation (30) to eliminate the first two terms in this expression, equation (29) to eliminate $\hat{c}_t(z)$ and multiplying the resulting expression by $(1-\gamma-\gamma\beta)(1-\gamma)$ gives

$$E_0\sum_{t=0}^{\infty} p(z)c(z)\beta^t\left[\gamma\hat{p}_t(z) - \gamma\beta x_{t+1} + \frac{1-\theta}{2}\hat{p}_t^2 + (\theta-1)(\hat{S}_t + \hat{\Upsilon}_t)\hat{p}_t(z)\right] + \text{ex. terms} + \mathcal{O}(||\xi,\gamma||^3). \quad (31)$$

Collecting the terms in the sum that involve $\hat{p}_t(z)$, x_t and $\hat{\Phi}_t = \hat{S}_t + \hat{\Upsilon}_t$ we can define

$$R(x_t, \hat{p}_t(z), \hat{S}_t) = \gamma\hat{p}_t(z) - \gamma x_t - \frac{1}{2}(\theta-1)\hat{p}_t^2(z) + (\theta-1)\hat{\Phi}_t\hat{p}_t(z) \quad (32)$$

for $t \geq 1$. This is the function in our model that corresponds to $R(x_t, \mu_t, \theta_t)$ in Athey et al. (2004). Mapping our notation into the notation used by Athey et al. (2004) we get that: $x_t = x_t$, $\mu_t = \hat{p}_t(z)$ and $\theta_t = \hat{\Phi}_t$. In the notation used by Athey et al. (2004), the firm's objective function is

$$R(x_t, \mu_t, \theta_t) = \gamma\mu_t - \gamma x_t - \frac{1}{2}(\theta-1)\mu_t^2 + (\theta-1)\theta_t\mu_t.$$

Notice that this function satisfies all the conditions required for the propositions in Athey et al. (2004) to be valid. Specifically, $R_x(x_t, \mu_t, \theta_t) = -\gamma < 0$, $R_{\mu\theta}(x_t, \mu_t, \theta_t) = \theta - 1 > 0$ and $R_{\mu\mu}(x_t, \mu_t, \theta_t) = -(\theta-1) < 0$.

The main difference between our results and the results in Athey et al. (2004) is that they consider a model in which $R(x_t, \mu_t, \theta_t)$ is the social welfare function, i.e. it is the objective of all the agents in the model. The fact that $R(x_t, \mu_t, \theta_t)$ in Athey et al. (2004) is the social welfare function entails that the resulting policy is socially optimal. Here we use the objective of the firm as our $R(x_t, \mu_t, \theta_t)$, which means that the resulting policy is not socially optimal but rather the best policy from the perspective of the firm. The proofs in Athey et al. (2004) do not rely on $R(x_t, \mu_t, \theta_t)$ being a social welfare function. Only their interpretation as solving for the socially optimal policy relies on this.

Given equation (32) and the following monotone hazard conditions: $(1-P(\hat{\Phi}_t))/p(\hat{\Phi}_t)$ is strictly decreasing in $\hat{\Phi}_t$ and $P(\hat{\Phi}_t)/p(\hat{\Phi}_t)$ is strictly increasing in $\hat{\Phi}_t$, Proposition 1 in Athey et al. (2004) shows that the pricing policy that is optimal from the perspective of the firm is static. Here $p(\hat{\Phi}_t)$ and $P(\hat{\Phi}_t)$ denote the pdf and cdf of $\hat{\Phi}_t$, respectively. We assume that $\hat{\Phi}_t \in [\underline{\hat{\Phi}}, \bar{\hat{\Phi}}]$.

Furthermore, Proposition 2 in Athey et al. (2004) shows that the firm's best pricing policy is either a constant price or it is a policy of bounded discretion, i.e.,

$$\hat{p}(z) = \begin{cases} \hat{p}^*(\hat{\Phi}; z) \text{ if } \hat{\Phi} \in [\underline{\hat{\Phi}}, \hat{\Phi}^*] \\ \hat{p}^*(\hat{\Phi}^*; z) \text{ if } \hat{\Phi} \in [\hat{\Phi}^*, \bar{\hat{\Phi}}] \end{cases} \tag{33}$$

where $\hat{p}^*(\hat{\Phi}; z)$ denotes the static best response of a firm with a desired price equal to $\hat{\Phi}$ and $\underline{\hat{\Phi}} \leq \hat{\Phi}^* \leq \bar{\hat{\Phi}}$.

To complete the description of the policy most prefered by the firm, we must calculate four things: 1) Under what conditions does the firm prefer a constant price? 2) What is the optimal constant price from the firm's perspective? 3-4) When the firm prefers to set its price according to equation (33), what is the optimal cutoff point $\hat{\Phi}^*$ and what is the firm's static best response $\hat{p}^*(\hat{\Phi}; z)$?

The remainder of this section draws heavily on appendix D in Athey et al. (2004). First, notice that the static best reponse of the firm solves $R_{\hat{p}(z)}(E\hat{p}(z), \hat{p}(z), \hat{\Phi}) = 0$. The solution is

$$\hat{p}^*(\hat{\Phi}, z) = \frac{\gamma}{\theta - 1} + \hat{\Phi}. \tag{34}$$

If the firm's pricing policy is of the form (33), then

$$E\hat{p}(z) = \int_{\underline{\hat{\Phi}}}^{\hat{\Phi}^*} \hat{p}^*(\hat{\Phi}, z)p(\hat{\Phi})d\hat{\Phi} + \int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} \hat{p}^*(\hat{\Phi}^*, z)p(\hat{\Phi})d\hat{\Phi}.$$

Using equation (34) to plug in for $\hat{p}^*(\hat{\Phi}, z)$ in this equation we get that

$$E\hat{p}(z) = \frac{\gamma}{\theta - 1} - \int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} (\hat{\Phi} - \hat{\Phi}^*)p(\hat{\Phi})d\hat{\Phi}.$$

Athey et al. (2004) show that the objective of the firm, $\int R(E\hat{p}(z), \hat{p}(z), \hat{\Phi})p(\hat{\Phi})d\hat{\Phi}$ may be written

$$R(E\hat{p}(z), \hat{p}^*(\underline{\hat{\Phi}}, z), \underline{\hat{\Phi}}) + \int_{\underline{\hat{\Phi}}}^{\hat{\Phi}^*} R_{\hat{\Phi}}(E\hat{p}(z), \hat{p}^*(\hat{\Phi}, z), \hat{\Phi})[1 - P(\hat{\Phi})]d\hat{\Phi}$$
$$+ \int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} R_{\hat{\Phi}}(E\hat{p}(z), \hat{p}^*(\hat{\Phi}^*, z), \hat{\Phi})[1 - P(\hat{\Phi})]d\hat{\Phi}.$$

Since $R_{\hat{\Phi}}(E\hat{p}(z), \hat{p}(z), \hat{\Phi}) = (\theta - 1)\hat{p}(z)$, this expression simplifies to

$$\gamma \int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} (\hat{\Phi} - \hat{\Phi}^*)p(\hat{\Phi})d\hat{\Phi} + (\theta - 1)\int_{\underline{\hat{\Phi}}}^{\hat{\Phi}^*} \hat{\Phi}[1 - P(\hat{\Phi})]d\hat{\Phi} + (\theta - 1)\int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} \hat{\Phi}^*[1 - P(\hat{\Phi})]d\hat{\Phi} + \text{ex. terms}.$$

Differentiating this with respect to $\hat{\Phi}^*$ and setting the resulting expression equal to zero yields

$$-\gamma \int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} p(\hat{\Phi})d\hat{\Phi} + (\theta - 1)\int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} [1 - P(\hat{\Phi})]d\hat{\Phi} = 0,$$

which is equivalent to

$$-\gamma[1 - P(\hat{\Phi}^*)] + (\theta - 1)\int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} [1 - P(\hat{\Phi})]d\hat{\Phi} = 0.$$

When $\hat{\Phi}^* < \bar{\hat{\Phi}}$, $1 - P(\hat{\Phi}^*) > 0$, so this last equation is equivalent to

$$-\gamma + (\theta - 1)\int_{\hat{\Phi}^*}^{\bar{\hat{\Phi}}} \frac{1 - P(\hat{\Phi})}{p(\hat{\Phi})} \frac{p(\hat{\Phi})}{1 - P(\hat{\Phi}^*)} d\hat{\Phi} = 0. \tag{35}$$

Notice that the second term on the left hand side of this equaiton is the conditional mean of $(1 - P(\hat{\Phi}))/p(\hat{\Phi})$ over the interval $[\hat{\Phi}^*, \bar{\hat{\Phi}}]$. Since $(1 - P(\hat{\Phi}))/p(\hat{\Phi})$ is strictly decreasing in $\hat{\Phi}^*$ (monotone hazard assumption), its conditional mean is also strictly decreasing in $\hat{\Phi}^*$. This implies that equation (35) has at most one interior solution. Since the expression on the left hand side of equation (35) is decreasing in both γ and $\hat{\Phi}^*$, it is furthermore the case that $\hat{\Phi}^*$ is decreasing in γ.

We have shown that equation (35) has at most one interior solutions. To show that such a solution in fact exists we must show that the left hand side of this equation is negative for $\hat{\Phi}^*$ close $\bar{\hat{\Phi}}$ and positive for $\hat{\Phi}^* = \underline{\hat{\Phi}}$. Notice that when $\hat{\Phi}^* \to \bar{\hat{\Phi}}$, $(1 - P(\hat{\Phi}))/p(\hat{\Phi}) \to 0$. This implies that for $\gamma > 0$ and $\hat{\Phi}^*$ close enough to $\bar{\hat{\Phi}}$, the left hand side of equation (35) is strictly less than zero. When $\hat{\Phi}^* = \bar{\hat{\Phi}}$, equation (35) is not defined. However, $\hat{\Phi}^* = \bar{\hat{\Phi}}$ is a solution to the equation above equation (35). However, since the expression on the left hand side of that equation is strictly negative for $\hat{\Phi}^* < \bar{\hat{\Phi}}$ in the neighborhood of $\bar{\hat{\Phi}}$, this is not a local maximum.

Athey et al. (2004) show that at $\hat{\Phi}^* = \underline{\hat{\Phi}}$ the left hand side of equation (35) becomes $-\gamma - \underline{\hat{\Phi}}$. Since $\underline{\hat{\Phi}} < 0$, this is positive for $\gamma \in (0, -\underline{\hat{\Phi}})$. So, there is an interior solution in this case. When

$\gamma > -\underline{\hat{\Phi}}$ there is no interior solution to equation (35). This implies that for this range of γ the firm's best policy is a constant price.

Finally, when $\gamma > -\underline{\hat{\Phi}}$ the firm chooses its constant price to maximize

$$\int_{\underline{\hat{\Phi}}}^{\bar{\hat{\Phi}}} R(E\hat{p}(z), \hat{p}(z), \hat{\Phi})p(\hat{\Phi})d\hat{\Phi}$$

subject to $E\hat{p}(z) = \hat{p}(z)$. The solution to this problem is $\hat{p}(z) = 0$.

B Second Order Approximations

B.1 A Derivation of a 2nd Order Approximation to the Firm's Value

Given the simplifying assumption that the firm's production function is linear we can substitute it into the expression for the firm's value and get

$$E_0 \sum_{t=0}^{\infty} M_{0,t}[p_t(z)c_t(z) - \frac{W_t}{A_t}c_t(z)],$$

Proposition 4 implies that in the steady state with full commitment

$$p(z) = \frac{\theta}{\theta - 1}\frac{W}{A},$$

where variables without subscripts denote steady state values. Notice furthermore that equation (11) implies that $C = (1-\gamma)c(z)$ and equation (12) implies that $(1-\gamma\beta)P = p(z)$. A second order Taylor series approximation of the value of the firm around the steady state of the solution to the firm's problem with commitment is given by

$$\begin{aligned} E_0 \sum_{t=0}^{\infty} \beta^t \Big[& c(z)(p_t(z) - p(z)) + \frac{1}{\theta}p(z)(c_t(z) - c(z)) + (p_t(z) - p(z))(c_t(z) - c(z)) \\ & - \frac{\theta - 1}{\theta}\frac{p(z)}{W}(W_t - W)(c_t(z) - c(z)) + \frac{\theta - 1}{\theta}\frac{p(z)}{A}(A_t - A)(c_t(z) - c(z)) \\ & + \frac{c(z)}{\beta^t}(p_t(z) - p(z))(M_{0,t} - \beta^t) + \frac{1}{\theta}\frac{p(z)}{\beta^t}(c_t(z) - c(z))(M_{0,t} - \beta^t) \Big] \\ & + \text{ex. terms} + \mathcal{O}(||\xi||^3), \end{aligned} \tag{36}$$

where "ex. terms" stands for terms that are exogenous to the firm's decision problem, ξ stands for a vector of the exogenous variables and $\mathcal{O}(||\xi||^3)$ denotes higher order terms.

The exposition of our results is simplified if we make a change of variables. Let $\hat{c}_t(z) = \log(c_t(z)/c(z))$ and define hatted versions of all other variables in the same way. Making use of the fact that

$$c_t(z) = c(z)\left(1 + \hat{c}_t(z) + \frac{1}{2}\hat{c}_t(z)\right) + \mathcal{O}(||\xi||^3),$$

we can rewrite equation (36) as

$$E_0 \sum_{t=0}^{\infty} p(z)c(z)\beta^t \left[\left(\hat{p}_t(z) + \frac{1}{2}\hat{p}_t(z)^2\right) + \frac{1}{\theta}\left(\hat{c}_t(z) + \frac{1}{2}\hat{c}_t(z)^2\right) + \hat{p}_t(z)\hat{c}_t(z) - \frac{\theta-1}{\theta}\hat{S}_t\hat{c}_t(z) \right.$$
$$\left. + \hat{p}_t(z)\hat{M}_{0,t} + \frac{1}{\theta}\hat{c}_t(z)\hat{M}_{0,t}\right] + \text{ex. terms} + \mathcal{O}(||\xi||^3), \quad (37)$$

where $\hat{S}_t = (\hat{W}_t - \hat{A}_t)$.

B.2 A Derivation of a 2nd Order Approximation to the Consumer Demand Curve

Notice that consumer demand—given by equation (12)—may be rewritten as

$$P_t C_t^{\frac{1}{\theta_t}} (c_t(z) - \gamma c_{t-1}(z))^{-\frac{1}{\theta_t}} = p_t(z) + E_t\left[\gamma M_{t,t+1} P_{t+1} C_{t+1}^{\frac{1}{\theta_{t+1}}} (c_{t+1}(z) - \gamma c_t(z))^{-\frac{1}{\theta_{t+1}}}\right].$$

A second order Taylor series approximation of this equation around the steady state of the solution to the firm's problem with commitment is given by

$$\begin{aligned}
&(P_t - P) + \frac{1}{\theta}PC^{-1}(C_t - C) - \frac{1}{\theta}Pc(z)^{-1}(c_t(z) - c(z)) + \frac{\gamma}{\theta}Pc(z)^{-1}(c_{t-1}(z) - c(z)) \\
&\quad - \frac{1}{\theta}Pc(z)^{-1}(P_t - P)(c_t(z) - c(z)) + \frac{1+\theta}{2\theta^2}Pc(z)^{-2}(c_t(z) - c(z))^2 \\
&\quad - \frac{1}{\theta^2}PC^{-1}c(z)^{-1}(C_t - C)(c_t(z) - c(z)) + \frac{1}{\theta^2}Pc(z)^{-1}(c_t(z) - c(z))(\theta_t - \theta) \\
&\quad = (p_t(z) - p(z)) - \frac{\gamma\beta}{\theta}Pc(z)^{-1}E_t(c_{t+1}(z) - c(z)) + \text{s.o.ex.terms} + \mathcal{O}(||\xi,\gamma||^3), \qquad (38)
\end{aligned}$$

where s.o.ex.terms denotes "second order exogenous terms" and $\mathcal{O}(||\xi,\gamma||^3)$ denotes terms that are third order (or higher) in $||\xi,\gamma||$. The norm $||\xi,\gamma||$ is simply meant to denote the standard Euclidian distance norm in (ξ,γ) space. As in the case of the expression for the value of the firm, we find it convenient to rewrite equation (38) in terms of the hatted variables. This yields

$$\left(\hat{c}_t(z) + \frac{1}{2}\hat{c}_t(z)^2\right) - \gamma\hat{c}_{t-1}(z) - \frac{1+\theta}{2\theta(1-\gamma)}\hat{c}_t(z)^2 - \theta\hat{P}_t - \hat{C}_t + \hat{P}_t\hat{c}_t(z) + \frac{1}{\theta}\hat{C}_t\hat{c}_t(z) - \hat{c}_t(z)\hat{\theta}_t$$
$$= -\theta(1 - \gamma - \gamma\beta)\hat{p}_t(z) - \frac{\theta}{2}\hat{p}_t(z)^2 + \gamma\beta E_t\hat{c}_{t+1}(z) + \text{s.o.ex.terms} + \mathcal{O}(||\xi,\gamma||^3), \ (39)$$

C The Sales Filter

Let p_t denote the observed price at time t and r_t denote the "regular" price at time t. The sales filter has 6 steps for each time period which should be considered in order (i.e. step 1 has precedence over step 2, etc.). However, for the first time period, the algorithm implementing the filter should start at step 3 (the first step not to refer to r_{t-1}). The steps of the filter are:

0. If $p_t = r_{t-1}$, then $r_t = r_{t-1}$.
1. If $p_t > r_{t-1}$, then $r_t = p_t$.
2. If $r_{t-1} \in \{p_{t+1}, ..., p_{t+J}\}$, then $r_t = r_{t-1}$.
3. If the set $\{p_t, p_{t+1}, ..., p_{t+L}\}$ has K or more different elements, then $r_t = p_t$.
4. Define $p_{max} = \max\{p_t, p_{t+1}, ..., p_{t+L}\}$ and $t_{max} = \text{first-time}\max\{p_t, p_{t+1}, ..., p_{t+L}\}$. If $p_{max} \in \{p_{t_{max}+1}, ..., p_{t_{max}+L}\}$, then $r_t = p_{max}$.
5. $r_t = p_t$.

The filter has three parameters to be chosen by its user: J and K. We chose these parameters to be $J = 8$, $K = 3$, $L = 3$.

The filter identifies sales as brief period of time when the price of the good drops below its regular price before returning to its old regular price or a new reoccuring regular price. A simpler filter would only identify sales as cases when the price returns to the original regular price. However, our filter counts brief discounts followed by changes in the regular price as sales.

The parameters J, K and L determine how conservative the filter is at assigning price variation to sales rather than variation in the regular price. If, e.g., $J = K = L = 3$ any price change lasting longer than 3 periods is counted as a change in the regular price and any time 3 or more prices are seen in four consecutive periods the filter assigns variation in the price to variation in the regular price, not sales. This means that if two different sales with different sales prices happen with one or two periods in between all the variation in price is assigned to the regular price. If J, K and L are assigned higher values, longer and more irregular sales within a short period are allowed.

The parameters we use imply that the maximum duration of sales is 3 periods if the price returns to the original "regular price" following a sale (i.e., a v-shaped sale) and 7 periods if the price returns to a new recurring regular price following the sale.

Perhaps the best way to convince the reader that our sales filter correctly identifies sales is to show what happens when we apply the filter to a few price series. Figures 1-3 provide three examples. In each figure we plot the price of a good and the regular price shifted up by $1. Two things stand out: 1) Most of the time, the filter works very well. It filters out all sales and only sales. 2) The filter is somewhat conservative in assigning price variation to sales rather than the regular price. In particular, very irregular patterns of sales are attributed to variation in the regular price rather than variation in the sale price. The most striking example of this is the price of Diet Coke in the period form last 1995 to mid 1996. During this period, the price of Diet Coke varied rather eratically and the sales filter was unable to identify a stable regular price. This type of error tends to increase the frequency of price changes and the number of unique values in the regular price series. Both of these effects work against the results we present in section 5.

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Table 1: Descriptive Statistics on Retail Price Adjustment

Product	Fraction of Weeks at the Regular Price	Fraction of Sales that Return to the Regular Price
Analgesics	0.954 (0.001)	0.926 (0.008)
Bath Soap	0.921 (0.003)	0.938 (0.014)
Bathroom Tissues	0.825 (0.004)	0.937 (0.007)
Beer	0.758 (0.003)	0.925 (0.005)
Bottled Juices	0.831 (0.002)	0.956 (0.003)
Canned Soup	0.892 (0.001)	0.957 (0.003)
Canned Tuna	0.882 (0.002)	0.947 (0.006)
Cereals	0.931 (0.001)	0.947 (0.005)
Cheese	0.812 (0.002)	0.945 (0.003)
Cigarettes	0.995 (0.001)	0.897 (0.040)
Cookies	0.868 (0.001)	0.958 (0.003)
Crackers	0.837 (0.002)	0.968 (0.004)
Dish Detergent	0.886 (0.002)	0.969 (0.004)
Fabric Softeners	0.904 (0.002)	0.947 (0.006)
Front-end-candies	0.896 (0.002)	0.968 (0.004)
Frozen Dinners	0.768 (0.004)	0.963 (0.004)
Frozen Entrees	0.845 (0.001)	0.961 (0.002)

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Product	Fraction of Weeks at the Regular Price	Fraction of Sales that Return to the Regular Price
Frozen Juices	0.813 (0.002)	0.966 (0.004)
Grooming Products	0.889 (0.001)	0.929 (0.004)
Laundry Detergents	0.908 (0.002)	0.951 (0.005)
Oatmeal	0.907 (0.003)	0.970 (0.007)
Paper Towels	0.836 (0.004)	0.946 (0.007)
Refrigirated Juices	0.766 (0.003)	0.934 (0.005)
Shampoos	0.900 (0.002)	0.935 (0.004)
Snack Crackers	0.827 (0.002)	0.947 (0.004)
Soaps	0.871 (0.003)	0.952 (0.006)
Soft Drinks	0.750 (0.001)	0.957 (0.001)
Toothbrushes	0.871 (0.002)	0.935 (0.006)
Toothpastes	0.887 (0.002)	0.936 (0.005)
Median	0.871	0.947

Note: Standard Errors are in parentheses. The total number of observations is 985,022. The regular price and sale prices of a good are identified using the sales filter that is discribed in appendix C. Estimates are based on pooled data from each category.

Table 2: Adjustment of Regular versus Sale Prices

Product	Frequency of Price Change: Regular Prices	Frequency of Price Change: Sale Prices	Number of Unique Prices as a Fraction of Total Weeks: Regular Prices	Number of Unique Prices as a Fraction of Total Weeks: Sales Prices
Analgesics	0.036 (0.001)	0.411 (0.013)	0.035 (0.001)	0.578 (0.019)
Bath Soap	0.026 (0.002)	0.354 (0.025)	0.031 (0.002)	0.531 (0.047)
Bathroom Tissues	0.110 (0.003)	0.491 (0.014)	0.064 (0.004)	0.359 (0.029)
Beer	0.063 (0.001)	0.200 (0.006)	0.040 (0.002)	0.195 (0.016)
Bottled Juices	0.084 (0.001)	0.454 (0.006)	0.053 (0.002)	0.404 (0.014)
Canned Soup	0.058 (0.001)	0.418 (0.007)	0.042 (0.001)	0.464 (0.016)
Canned Tuna	0.069 (0.002)	0.304 (0.008)	0.046 (0.003)	0.331 (0.013)
Cereals	0.069 (0.001)	0.528 (0.010)	0.061 (0.001)	0.668 (0.014)
Cheeses	0.111 (0.001)	0.530 (0.005)	0.080 (0.007)	0.395 (0.010)
Cigarettes	0.036 (0.001)	—	0.053 (0.001)	0.580 (0.037)
Cookies	0.046 (0.001)	0.500 (0.005)	0.034 (0.001)	0.426 (0.009)
Crackers	0.065 (0.001)	0.445 (0.008)	0.044 (0.002)	0.349 (0.013)
Dish Detergent	0.054 (0.001)	0.453 (0.011)	0.047 (0.002)	0.434 (0.018)
Fabric Softeners	0.057 (0.001)	0.404 (0.011)	0.045 (0.003)	0.495 (0.023)
Front-end-Candies	0.028 (0.001)	0.344 (0.008)	0.024 (0.001)	0.338 (0.016)
Frozen Dinners	0.066 (0.002)	0.551 (0.011)	0.040 (0.003)	0.432 (0.022)
Frozen Entrees	0.054 (0.001)	0.495 (0.006)	0.039 (0.001)	0.446 (0.007)

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	Frequency of Price Change		Number of Unique Prices as a Fraction of Total Weeks	
Product	Regular Prices	Sale Prices	Regular Prices	Sales Prices
Frozen Juices	0.081 (0.002)	0.522 (0.009)	0.051 (0.002)	0.344 (0.011)
Grooming Products	0.034 (0.001)	0.497 (0.007)	0.036 (0.001)	0.442 (0.011)
Laundry Detergents	0.061 (0.001)	0.425 (0.009)	0.049 (0.003)	0.538 (0.027)
Oatmeal	0.071 (0.002)	0.530 (0.019)	0.062 (0.004)	0.607 (0.029)
Paper Towels	0.086 (0.003)	0.482 (0.015)	0.045 (0.004)	0.301 (0.023)
Refrigerated Juices	0.133 (0.002)	0.635 (0.008)	0.089 (0.005)	0.447 (0.016)
Shampoos	0.043 (0.001)	0.443 (0.010)	0.038 (0.001)	0.443 (0.013)
Snack Crackers	0.073 (0.001)	0.529 (0.007)	0.051 (0.002)	0.428 (0.013)
Soaps	0.051 (0.002)	0.510 (0.011)	0.039 (0.003)	0.449 (0.026)
Soft Drinks	0.076 (0.001)	0.652 (0.004)	0.042 (0.001)	0.309 (0.006)
Toothbrushes	0.049 (0.001)	0.406 (0.011)	0.045 (0.002)	0.403 (0.016)
Toothpastes	0.056 (0.001)	0.492 (0.009)	0.048 (0.001)	0.443 (0.013)
Median	0.061	0.487	0.045	0.434

Note: Standard Errors are in parentheses. The total number of observations is 985,022. The regular price and sale prices of a good are identified using the sales filter that is described in appendix C. The frequency of price change is calculated by dividing the total number of price changes by the total number of weeks. The statistics in columns three and four are calculated by first dividing the number of unique regular or sale prices observed for a product by the total number of weeks at the regular price or on sale and then averaging within categories.

Table 3: Evidence of Price Commitments

Company	Industry	Company Description	Date	Quote
Industrial				
Auto Suppliers				
Steel				
Indian Steel Alliance	steel	organization represents 5 leading steelmakers	5-Mar-04	Steelmakers in India will not increase prices of hot rolled steel coils until end of June even if input costs rise during this period, the chairman of an industry body (Indian Steel Alliance) said on Thursday
Tata Steel	steel	India	24-Aug-04	B Muthuraman, managing director, Tata Steel, said: "We will not increase prices for both our direct customers as well as retail customers till March 2005." Tata Steel announcement assumed significance against the backdrop of rising global steel prices and large international steel companies like Arcelor and Posco already annoucing price hikes for the next quarter.
Other				
Siemens	equipment		31-Dec-69	Siemens make a commitment not to increase the price for the service indefinitely
Pioneer Hi-Bred International	agricultural products		29-Sep-98	announced it will not raise prices of its corn and soybean seed products in calendar year 1999, due to the "challenging economic conditions faced by US and Canadian farmers"
Sarel, brand of Schneider Electric	fences		1-Jun-01	Accompanying the catalogue is a new price list, the most important feature of which is what hasn't changed - the prices! In fact, Sarel, a brand of Schneider Electric, has had no price increases for more than five years, and no price changes are expected in the foreseeable future. "Our new catalogue and stable prices both, in their own way, demonstrate our commitment to enclosure users," said Brian O'Donoghue, marketing manager. "We have made a substantial investment in ensuring that our catalogue guides customers toward the most appropriate and most economical enclosure choices. When they've made their choice, the exceptional stability of our prices means that they know not only that they're getting superb value for money today, but also that they will continue to do so in the future."

Computer Related

Web Hosting			
Tech trade Internet Services	web hosting	29-Jan-05	Price Freeze Guarantee. Same price. Forever.
Infinity Hosting	web hosting	29-Jan-05	Price Promise: the price you paid when you opened your account iw the price you will always pay. No price increases no extra charges ever….No contract…cancel your hosting account…at any time
hostup.com	web hosting	29-Jan-05	we will never, ever increase the pricing of hosting plans…you will always pay the same fee for your hosting account
A1-hosting	web hosting	1-Dec-04	Life Time Price Guarantee…there will be no Price increases for the life of the time that you host with us
Cloch	web hosting	1-Dec-04	Price Promise: Cloch Internet will not raise the price of your hosting plan, even if the price increases for new customers
BurningBulb.net	web hosting	3-Dec-04	Price Freeze Guarantee. Our clients take comfort in knowing that regardless of our future pricing policies, their monthly fee will always remain the same. As our policies change for future accounts, current accounts continue to host at the same monthly fee charged at the time their account was setup.
Other			
DSLExtreme	internet services	3-Dec-04	Price Freeze Guarantee…Choose one of our exclusive Price Freeze Guarantee subscriptions. Clients who select this option will enjoy one low price for as long as they choose to keep the service. Your Price will never go up!
Optimum Online	cable internet	Nov-04	Cablevision Systems Corp. has announced that it will freeze prices for its Optimum Online high-speed Internet service in 2005. The announcement comes when the number of customers for that service has increased despite stepped-up competition, including discount prices, from phone companies including Verizon Communications.
Comodo	internet security	30-Oct-04	"We want to assure all our customers that our prices remain frozen,"; states Paul Tourret, Managing Director of Comodo Limited,"We launched Instant SSL several months ago as the market leader in low-cost, fully validated, fully supported high quality SSL Certificates. The recent price increases from Thawte and GeoTrust only strengthen our unique position in this market - through Instant SSL we ensure that high quality SSL webserver security will remain affordable.";

Power and Electricity

Electric Utilities

Powerco	utility		4-Jan-02	Powerco, New Zealand’s third largest electricity and gas utility has implemented a 12 month voluntary price freeze from 1 April 2002 for its electricity lines charges for all its residential consumers in the central and lower North Island.
npower	utility		29-Jan-05	With npower you’ll see no increase in your electricity and gas prices throughout the whole of 2005, providing there are no increases imposed by any governmental, statutory or licensing authority.
Bangor Hydro-Electric Company	utility	State of Maine utility	10-Jul-96	commitment not to raise prices

Oil and Gas

Bord Gais	utility	Bord Gáis Éireann (Bord Gáis) is a statutory body that was established under the 1976 Gas Act. The company is responsible for the transmission, distribution and supply of natural gas in Ireland. Bord Gáis, which is wholly owned by the Irish Government, employs over 800 staff and is headquartered at Gasworks Road, Cork.	29-Jun-00	Despite substantial increases in the supply cost of natural gas during the year, prices to consumers were not increased, in line with the company's commitment to maintain prices at existing levels until at least 2003. Natural gas prices for residential customers have not been increased since the mid-1980s.
Chinese Petroleum Corp	gas and oil	Taiwan	1-Apr-04	"will not raise prices before May 20"
Petron Corporation	diesel		? 2003	promised not to increase its prices any further for the rest of the year
Gazprom	gas and oil	Russia's oil and gas giant	3-Nov-99	Gazprom, Russia's oil and gas giant, does not intend to raise natural gas prices for its Russian clients this year, chairman of the company's board of directors Rem Vyakhirev said.

Other

ABB	utility supplier	ABB is a leader in power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact. The ABB Group of companies operates in around 100 countries and employs around 105,000 people.	25-May-04	In order to further strengthen our ties with our OEM customers, ABB will not be increasing prices on OEM medium voltage products. We will maintain the current price levels through the end of 2004, barring any further drastic changes in material costs
Pharmaceuticals				
GlaxosmithKline	pharmaceutical		Jul-02	will not raise wholesale prices of HIV drugs until January 2004. This will help low-income people who are uninsured or underinsured and rely on state programs and federal funding for their medications
Pfizer	pharmaceutical		Mar-02	2 year freeze on anti-retrovirals
Publishing				
Inspec	bibliographic services	Inspec is the leading English-language bibliographic information service providing access to the world's scientific and technical literature in physics, electrical engineering, electronics, communications, control engineering, computers and computing, information technology, production, manfacturing and mechanical engineering.	2001	INSPEC is pleased to announce a price freeze for 2002. This means no price increase for standalone customers and some networking customers will see a slight decrease.
Serials Solutions	library services	Serials Solutions Inc. provides complete e-journal access services to over 1000 libraries worldwide	19-Aug-03	Seattle, WA – August 19, 2003. Serials Solutions, Inc. announced today that it is freezing its 2003 price schedule and offering additional price breaks to keep services accessible for all libraries.

Consumer Goods

DHA Lighting	lighting	24-Jun-05	DHA Lighting has frozen prices on all products this year. The leading manufacturer of gobos, moving lighting effects, projection slides and creator of the Digital Light Curtain is holding its 2002 prices into 2003.
Marvel	comic books	23-May-02	Marvel CEO Bill Jemas began today's press conference by swiping a line from Bush the Elder and declaring, "Read my lips, we will not raise prices." The hastily called conference call with the comic press was arranged to provide a quick Marvel response to price increases on 20 books announced by DC Comics earlier in the week. Though Jemas did note that many companies traditionally took advantage of price hikes by the competition to raise prices on their own goods, he promised "that unless something drastic happens to the contrary, we will hold price indefinitely."
Jaguar	auto	15/10/1998	Speaking today at the Sydney International Motor Show 1998 industry day, Mr Danny Rezek, managing director of Jaguar Australia, said that:"Since its inception in 1922, Jaguar Cars has espoused a philosophy of offering customers excellent value for money. Jaguar Australia's commitment to this philosophy is evident in our announcement today of a price freeze on all Jaguar models for the next six months. This price freeze is testimony to our serious commitment to ensure our customers continue to receive best-in-class value," said Mr Rezek.
Mitsubishi South Africa	auto	23-Jun-05	Mitsubishi recently announced that it will not increase its prices for the remainder of 2001 and will only look at increasing prices in 2002.
Revlon	consumer goods	9-Oct-00	Revlon Inc. (NYSE: REV) today announced an innovative change to the way it does business with its U.S. retail partners to drive market growth and emphasize mutual success. In addition to the trade terms, the Company also announced a commitment not to raise prices for its retail partners in 2001.
Needham Junction ice cream	retail	5-May-04	In an article investigating the likelihood of future ice cream price increases: Around the middle of April…Turransky hiked the price of a small soft-serve ice cream cone...Turransky…stressed that he works with a printed menu, that he's already printed this season's and he won't be raising prices again
Apple Computer Inc	ipod music	1-Dec-04	Apple Computer Inc. on Friday flatly denied a report that the computer maker was planning to raise prices for songs bought on its popular iTunes online music store... "These rumors aren't true," said Apple spokeswoman Natalie Sequeira. "We have multiyear agreements with the labels and our prices remain 99c a track."

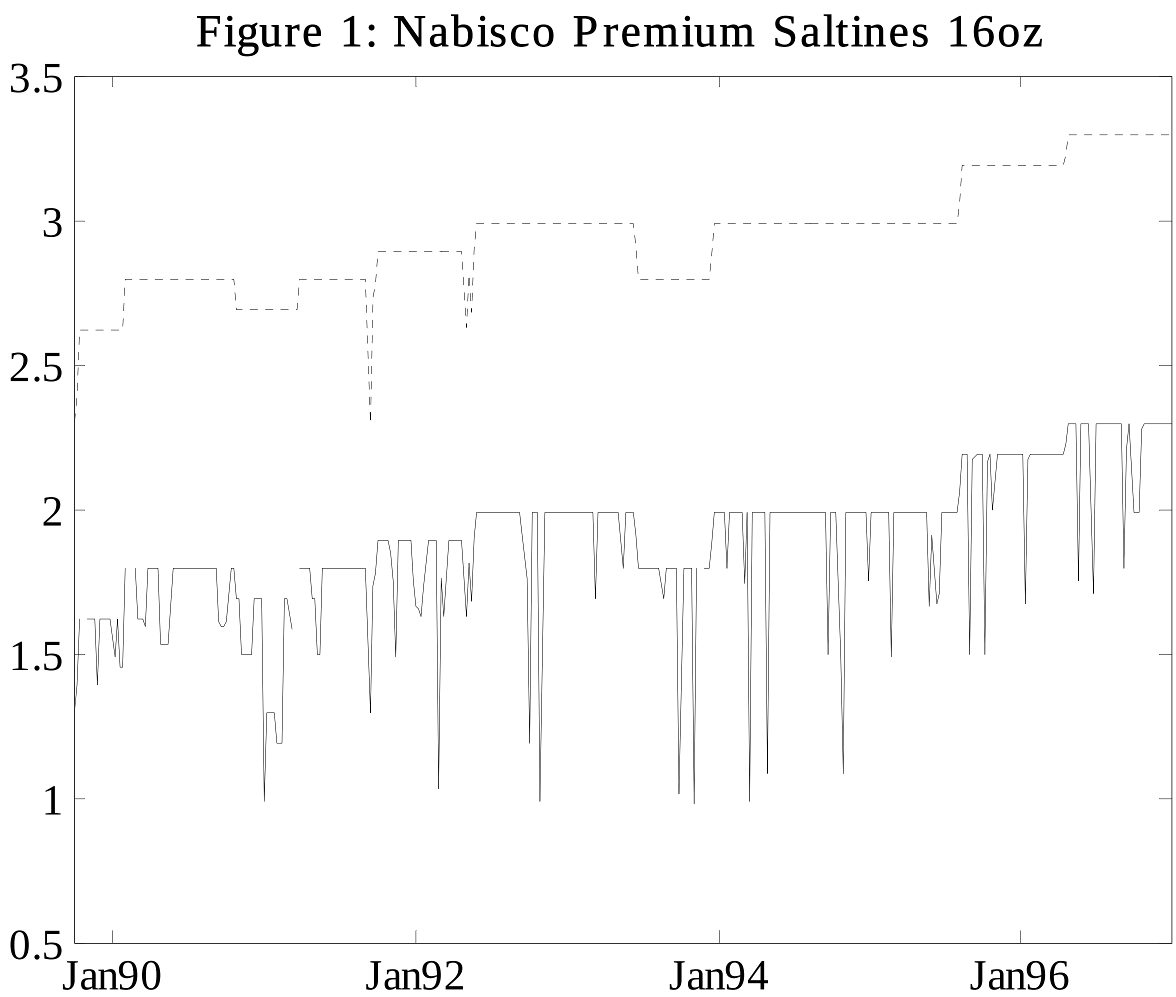
Consumer Services

Telephone				
Illonois Bell Telephone Company	telephone		6/26/2004	Price protection which guarantees no price increases for the duration of the 12, 24, or 36 month plan
Bell	telephone		6/10/2004	SBC and other Bells have pledged not to increase wholesale prices until 2005
Citzens Communications co	telephone		6/23/1905	proposed agreement to purchase lines in rural Colorado: proposal included guarantee to "maintain current prices for at least a year"
Cell Phone				
Cantel Amigo	cell phone	Canada cell phone	11/13/1997	price guarantee: We promise no price increases and the flexibility to change plans if you need to, no long term contract
Healthcare				
Palmetto Health	healthcare	integrated healthcare delivery system	6/18/1996	Following merger, "guarantees that the new system will have no price increases for five years"
BUPA Ireland	healthcare	BUPA Ireland is part of BUPA, a global health and care organisation with members in over 190 countries. BUPA have been committed to Irish healthcare for more than 15 years.BUPA Ireland is a not-for-profit organisation.	7/9/2002	will not be increasing prices to customers this year
Other (Small)				
Color Express	film		1/1/2005	Our published price list is one of our commitments. We provide consistent, "no surprises" pricing for our customers. Once we publish our price list, our track record proves that we commit to those prices; it's not uncommon to maintain prices for one to two years barring significant increases in the paper industry. Take a look at other published prices, and you will find revisions sometimes as frequently as every 3 - 6 months. Even if the competition's prices are "slashed", doesn't it make you wonder?
Bravo Software	software		Sep-02	This feature is called "Price Lock". Price Lock will allow you to purchase additional add-ons for the same price as when you joined the program. No price increases ever, for as long as you are a Customer Care member.

Satin Ivy Laundry Service	laundry		Jan-05		We offer a personalised service at affordable prices. Once accepted, our prices are set for 12 months – in fact we rarely increase prices even then, unless the purchase price of linen is increased.
Robins School of Motoring	driving instruction		1/1/2005		On the FAQ page: Q. How often do you increase your prices? A. I try to keep my rates as competitive as possible and rarely increase prices, this will depend mainly on the increase in the price of fuel and the general economy, over the last two years I have only increased my prices once by £1

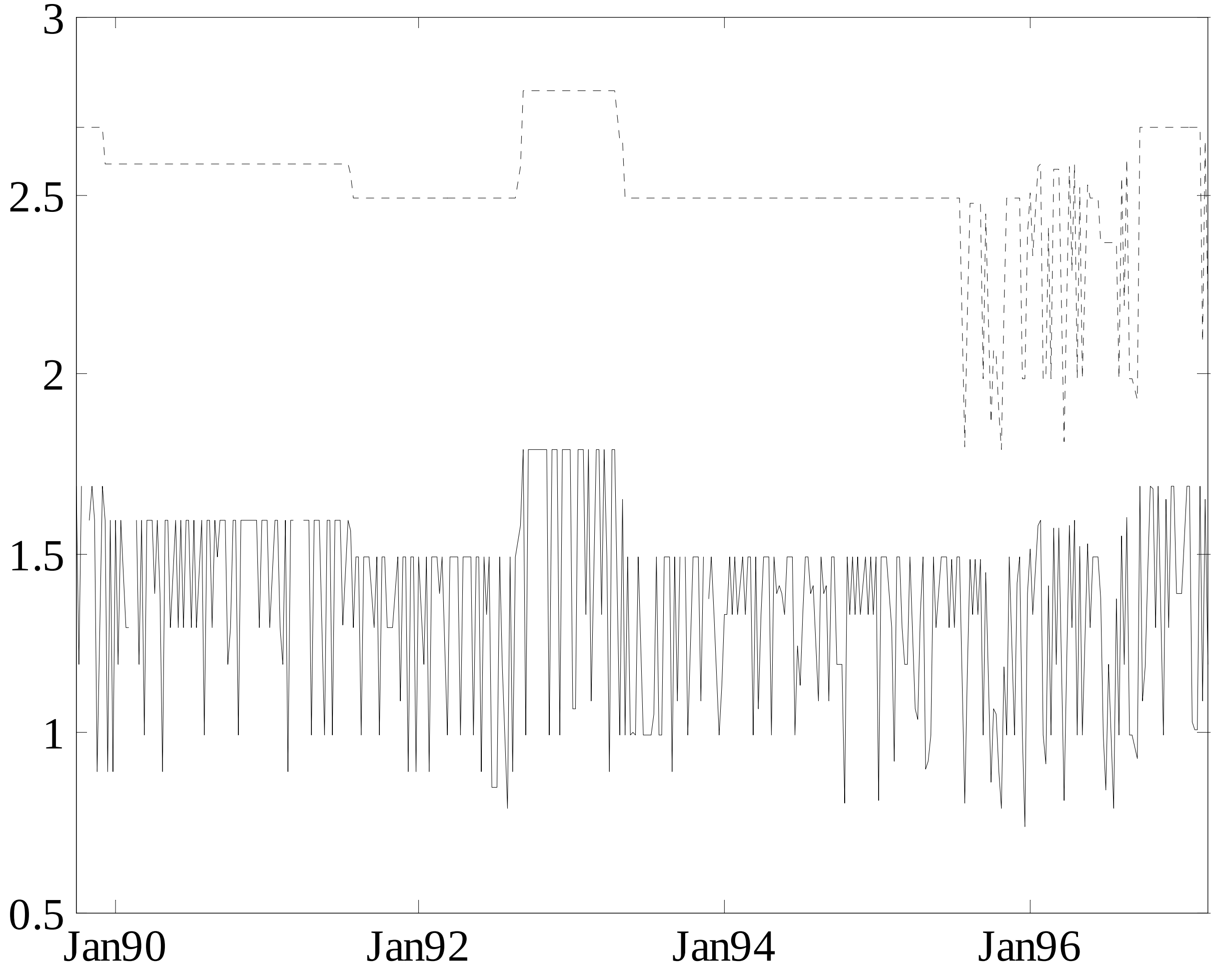
University Procurement

Monash University	procurement	procurement of information technologies	Oct-04		The Universit requires that Suppliers provide a firm price period of at least twelve (12) months from the date of execution of a formal agreement…During the firm price period the Supplier guarantees not to increase prices….
Harvard University	procurement	office products procurement from Staples	1/1/2005	*	Information based on an interview with the Harvard procurement manager: Staples prices fixed during the year for top 200(?) products



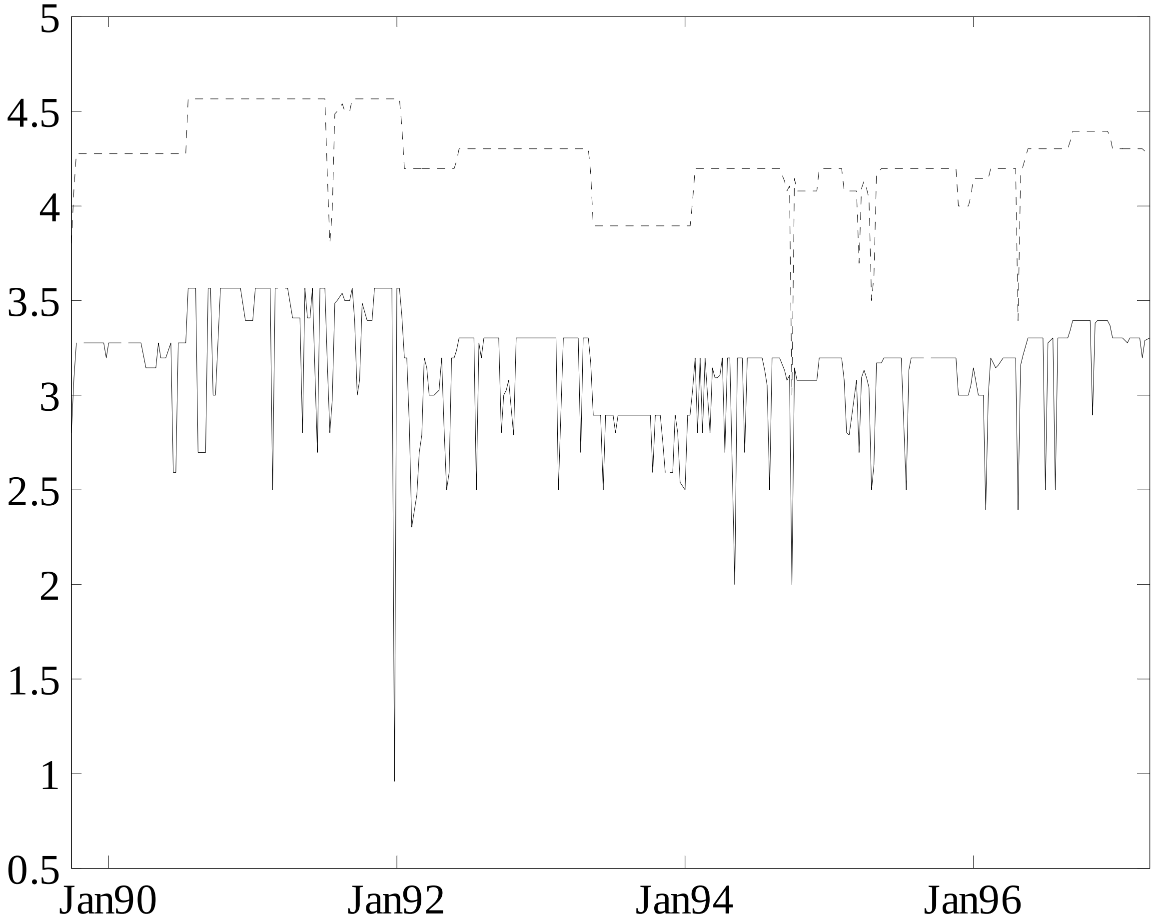
The solid line is the price of Nabisco Premium Saltines. The dotted line is the regular price of Nabisco Premium Saltines shifted up by $1.

Figure 2: Diet Coke 2L



The solid line is the price of Diet Coke 2L. The dotted line is the regular price of Diet Coke 2L shifted up by $1.

Figure 3: Kraft Singles 16oz



The solid line is the price of Nabisco Premium Saltines. The dotted line is the regular price of Nabisco Premium Saltines shifted up by $1.