Habit Persistence, Market Power and Policy Selection

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Abstract

This paper examines the behavior of a monopolist in a framework where consumer preferences display habit persistence. We show that, in the absence of precommitment, output and price setting policies yield different outcomes in terms of equilibrium prices and allocations. Instrument selection determines the strategic properties of the intra-personal game: from the viewpoint of the firm, current and future quantities are strategic complements, while current and future prices are strategic substitutes. We analyze a simple two-period model and an infinite horizon model. In both cases, we find that price targeting allows the monopolist to attain higher equilibrium profits.

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1 Introduction

In their pioneering work, Becker and Murphy (1988) study addictive behavior by introducing habits in a rational choice framework. Since then, there has been a surge in literature employing non-separable preferences[1]. Habit formation implies a link between current marginal utility and past consumption, which can explain several important economic phenomena both at the micro and macro levels. Examples of the former are binging behavior and the demand for alcohol or cigarettes (Chalopupka (1991), Becker, Grossman, and Murphy (1994)). The latter include the equity premium puzzle and the responses of consumer spending and inflation to monetary-policy actions (Constantinides (1990) and Fuhrer (2000), respectively).

As first noted by Pollak (1970), habit-based preferences give rise to inherently dynamic demand functions: present consumption levels depend on past and current prices, as well as on expectations regarding future market policies. Thus, producers of addictive goods face an intertemporal trade-off. By boosting current sales, they can speed up habit formation, which in turn will generate higher sales tomorrow. Becker, Grossman, and Murphy (1994) note that addictive consumption has interesting implications for the behavior of non-competitive firms. Expectations of future market conduct give rise to dynamic inconsistency issues: firms' inability to pre-commit creates a strategic conflict between the current decision maker and her future selves. Time-consistent market policies must account for this internal conflict, which constrains firms' choices and adversely affects profits.

This paper studies the implications of habit formation for the market power of monopolistic firms. In particular, we explore the effect of instrument selection on firm conduct and profitability. We challenge the standard hypothesis that producers follow output strategies. In the absence of precommitment, this assumption is rather ad-hoc: our analysis shows that it is not as innocuous as it seems. Therefore, the modeler's choice of the firms' decision variables should be contingent on the nature of the habit-forming good.

It should be noted that, under full precommitment, the issue of instrument selection is irrelevant. With binding contracts, price postings, or strong reputational mechanisms in place, output policies are equivalent to pricing policies. However, when up-front precommitment is not feasible, these decision variables generate different market outcomes in terms of equilibrium prices, quantities and profits. The intuition is that if consumer preferences exhibit distant complementarities, current marginal profit will be increasing in expected future output. Thus, a monopolist will perceive current and future production levels as intertemporal strategic complements. On the other hand, price targeting implies that the

[1]For a detailed survey of literature on habit persistence, see Messinis (1999).

current monopolist will compete with her future selves in terms of strategic substitutes. In intra-personal games, where all players are agents of a single decision maker, it is plausible that some degree of cooperation will emerge in equilibrium. Since competition in strategic substitutes is usually more benign and translates into higher equilibrium profits, the firm is likely to adopt price targeting.

With long planning horizons (both finite and infinite), time-consistent policies are often derived using a recursive formulation of the decision problem, in which history is summarized by state variables. Applying dynamic programming techniques to the monopolist's pricing problem can be difficult, as the current demand for a habit forming good may depend on the sequence of all past and future prices. While output targeting may be easier to formulate recursively, the derived equilibria will be implausible if a simple change in the decision variable enables firms to attain higher payoffs in each period. Moreover, this paper provides an example where both output and price setting can be defined recursively. When such transformations of the state and policy spaces are possible, modeling decisions need to carefully account for the strategic properties of policy instruments, as these can have important repercussions for market conduct and performance.

The few papers that study monopolistic production of habit-forming goods typically assume that firms implement output policies. Driskill and McCafferty (2001) use a continuous time setting to explore the effect of habit persistence in monopolistic and oligopolistic industries. They find that, in the absence of precommitment, industry profits may be higher under less concentrated market structures. Fethke and Jagannathan (1996) develop a model with consumers of two types: those with habits and those without. They show that when firms choose output levels, steady state consumption is lower under a time-consistent monopoly than under perfect competition or monopoly commitment. The strength of habits and the fraction of habitual consumers does not affect the outcomes under competition and monopoly commitment.

More generally, our results are related the literature on disadvantageous market power. Karp (1996) and other authors have shown in various settings that the inability to precommit will limit the decision-maker's discretion. The issue of time-consistent market policies has also gained significant prominence in the context of durable goods monopolies. In these models, a purchasing decision provides consumers with a stream of benefits over time. It has long been recognized that durability creates expectations of future policies that adversely affect market power (Coase (1972)). However, under the standard assumptions, producers of durable goods will view output levels as strategic substitutes (instead of complements). The majority of papers in this field (e.g. Bulow (1982), Stokey (1981)) correctly focus on output policies, which yield higher equilibrium profits relative to price targeting.

The remainder of the paper is organized as follows: Section 2 presents a simple two-period model of a monopolist who produces an addictive good. Consumers' preferences are assumed to exhibit distant complementarities. This setting enables us to illustrate the intuition underlying our results: we show that, in the absence of precommitment, the implementation of pricing policies will amount to an intra-personal game in strategic substitutes, while output policies imply competition in strategic complements. Thus, a time-consistent monopolist can attain higher profits if she maximizes her profits with respect to prices instead of quantities. Section 3 analyzes an infinite horizon model, suitably modified to allow for a recursive representation of both the price and the output setting problems. The results obtained in the two-period setting also hold in the infinite horizon case. Section 4 concludes the paper.

2 The two-period model

In this section, we use a simple two-period setting to compare the implications of instrument selection in an environment of habit persistence. We introduce addiction in the model by adopting a preference structure similar to Becker and Murphy (1988). The monopolist's optimal precommitment and time-consistent policies are characterized in Sections 2.3 and 2.4, respectively.

2.1 Setup

2.1.1 Preferences

Consider an industry where a representative consumer derives utility from two goods: a numeraire good m, and a habit forming good, x. We assume quasi-linear utility, which allows us to disregard income effects: the demand for x will depend only on relative prices. Without loss of generality, suppose that consumption of the numeraire takes place only in period 1. The addictive good is consumed in both periods.

Due to habit formation, the marginal utility derived from x in the second period depends on the amount consumed in period 1. Following Carroll (2000), we adopt a "subtractive habit specification"[2]:

$$U(m, x_1, x_2; \psi) = m + v(x_1) + \delta u\left(x_2 - \psi x_1\right), \tag{1}$$

where $v(\cdot), u(\cdot)$ are twice differentiable and concave felicity functions, δ is the discount factor and subscripts $t = 1, 2$ refer to time. The parameter ψ reflects the strength of habit persis-

[2]See Bossi and Gomis-Porqueras (2006) for a study on the differences between alternative formulations of habit persistence in the literature.

tence. We consider values of $\psi \in [0, 1]$, so that current marginal utility is increasing in past consumption. We also impose the condition that $\psi < \frac{x_2}{x_1}$ so that the effective consumption in the second period is positive. Note that

$$\frac{\partial^2 U}{\partial x_2 \partial x_1} = -\delta\psi u''\left(x_1 - \psi x_2\right).$$

Thus, using the terminology of Becker and Murphy (1988), x_1 and x_2 exhibit distant complementarities. This preference specification is often used to capture addiction: the higher the period-1 consumption level, the more consumption is required in the following period to derive a given level of utility.

The consumer faces the budget constraint $m + p_1 x_1 + p_2 x_2 = w$, where p_t denotes the price of good x in period t and w is lifetime wealth. The price of m is normalized to 1. Standard utility maximization yields the following inverse demands:

$$p_1(x_1, x_2) = v'(x_1) - \psi\delta u'\left(x_2 - \psi x_1\right), \quad p_2(x_1, x_2) = \delta u'\left(x_2 - \psi x_1\right). \tag{2}$$

From (2) we obtain the dynamic demand system:

$$x_1(p_1, p_2) = v'^{-1}(p_1 + \psi p_2), \quad x_2(p_1, p_2) = u'^{-1}(p_2/\delta) + \psi v'^{-1}(p_1 + \psi p_2). \tag{3}$$

In accordance with Becker and Murphy (1988) and Singh and Vives (1984), we assume linear-quadratic felicity functions. The linearity of the implied demand schedules substantially simplifies computations. In particular, we assume that:

$$U(m, x_1, x_2; \psi) = m + \alpha x_1 - \frac{1}{2}x_1^2 + \delta\left(\alpha(x_2 - \psi x_1) - \frac{1}{2}(x_2 - \psi x_1)^2\right), \tag{4}$$

where $\alpha > 0$ is a taste parameter. This functional form yields inverse demands

$$p_1(x_1, x_2) = \alpha - \delta\alpha\psi - (1 + \delta\psi^2)x_1 + \delta\psi x_2, \quad p_2(x_1, x_2) = \delta\alpha + \delta\psi x_1 - \delta x_2, \tag{5}$$

which correspond to the following demand system:

$$x_1(p_1, p_2) = \alpha - p_1 - \psi p_2, \quad x_2(p_1, p_2) = \alpha + \alpha\psi - \psi p_1 - \frac{p_2(1 + \delta\psi^2)}{\delta}. \tag{6}$$

2.1.2 Firms

The habit forming good is manufactured by a single firm. In the beginning of each period, the firm announces the current value of its policy instrument (prices or output levels) and then buyers make their consumption decisions. Let $\{z_t\}$ be the policy instrument adopted by the firm: $\{z_t\}_{t=1}^{\infty} = \{p_t\}_{t=1}^{\infty}$ or $\{z_t\}_{t=1}^{\infty} = \{x_t\}_{t=1}^{\infty}$. We will use $\pi_t \in \{\widehat{\pi}_t, \widetilde{\pi}_t\}$ to denote the corresponding instantaneous payoff function and $\Pi \in \{\widetilde{\Pi}, \widehat{\Pi}\}$ to denote the lifetime profits at period 1.

For simplicity, assume that the monopolist does not incur production costs.[3] Using (5) and (6), we can write instantaneous profits as functions of either output levels or prices:

$$\begin{aligned} \widehat{\pi}_1(x_1, x_2) &= p_1(x_1, x_2)x_1, \quad \widehat{\pi}_2(x_1, x_2) = p_2(x_1, x_2)x_2 && (7) \\ \widetilde{\pi}_1(p_1, p_2) &= p_1 x_1(p_1, p_2), \quad \widetilde{\pi}_2(p_1, p_2) = p_2 x_2(p_1, p_2). && (8) \end{aligned}$$

Accordingly, the period-1 lifetime profits are given by:

$$\widehat{\Pi}(x_1, x_2) = \widehat{\pi}_1(x_1, x_2) + \delta\widehat{\pi}_2(x_1, x_2), \qquad \widetilde{\Pi}(p_1, p_2) = \widetilde{\pi}_1(p_1, p_2) + \delta\widetilde{\pi}_2(p_1, p_2). \tag{9}$$

Note that utility specification (4) implies

$$\frac{\partial^2 \widehat{\pi}_1}{\partial x_1 \partial x_2} = \delta\psi^2, \quad \frac{\partial^2 \widehat{\pi}_2}{\partial x_1 \partial x_2} = \delta\psi, \quad \frac{\partial^2 \widetilde{\pi}_1}{\partial p_1 \partial p_2} = -\psi, \quad \frac{\partial^2 \widetilde{\pi}_2}{\partial p_1 \partial p_2} = -\psi.$$

Thus, if preferences exhibit distant complementarities ($\psi > 0$) and the monopolist is unable to precommit up-front, her period-1 and period-2 selves will perceive output levels as strategic complements and prices as strategic substitutes.

2.2 Precommitment policies

First, suppose that in period 1 the firm can precommit to future policies. Under full precommitment, the monopolist is not constrained by consumer expectations, thus her profit would exceed the payoff she can attain in any time-consistent equilibrium.

This problem is reminiscent of static price discrimination in two interlinked markets. The optimal precommitment policies, z_1 and z_2, solve:

$$\frac{\partial \Pi}{\partial z_1} = 0, \ \frac{\partial \Pi}{\partial z_2} = 0.$$

In our linear-quadratic example, the optimal precommitment quantities and prices are:

$$x_1^{PC} = \frac{\alpha(2 - \delta\psi + \delta^2\psi)}{4 + 2\delta\psi^2 - \delta^2\psi^2 - \psi^2}, \qquad x_2^{PC} = \frac{\alpha(\psi - \delta\psi^2 + \delta\psi + 2\delta + \delta^2\psi^2)}{\delta(4 + 2\delta\psi^2 - \delta^2\psi^2 - \psi^2)} \tag{10}$$

[3] This assumption is relaxed in the next section.

$$p_1^{PC} = \frac{\alpha(2 - \delta\psi - \delta^2\psi + \delta\psi^2 - \delta^2\psi^2)}{4 + 2\delta\psi^2 - \delta^2\psi^2 - \psi^2}, \quad p_2^{PC} = \frac{\alpha(2\delta - \psi + \delta\psi)}{4 + 2\delta\psi^2 - \delta^2\psi^2 - \psi^2}. \tag{11}$$

Substituting (10) and (11) into (5) and (6), we obtain:

$$x_1^{PC} = x_1(p_1^{PC}, p_2^{PC}), \quad x_2^{PC} = x_1(p_2^{PC}, p_2^{PC}), \quad p_1^{PC} = p_1(x_1^{PC}, x_2^{PC}), \quad p_2^{PC} = p_2(x_1^{PC}, x_2^{PC}).$$

Thus, under precommitment the equilibrium outcomes are equivalent, regardless of the firm's choice variable.

2.3 Time-consistent policies

Next, we assume away precommitment and focus on the time-consistent output and pricing strategies. Consumers' expectations of future market policies impose a constraint on the current decision maker, which prevents her from attaining the precommitment optimum. The policy prescribed by her precommitment plan will create an incentive for the monopolist to revise her choice in the subsequent period. She correctly anticipates future temptations to deviate and responds strategically. Thus, a time-consistent decision-maker is essentially playing a Stackelberg game against her future self.

To determine the equilibrium of this intra-personal game, we use backward induction. Once period 2 is reached, past events will be considered irrelevant. At this point, the monopolist disregards the effect of her decisions on the period-1 profits: she would choose z_2 to maximize $\pi_2(z_1, z_2)$. Maximization with respect to output and price, respectively, gives us:

$$x_2(x_1) = \frac{\alpha + \psi x_1}{2}, \quad p_2(p_1) = \frac{\alpha + \alpha\psi - \varphi p_1}{2\delta\psi^2 + 2}.$$

In period 1, the decision maker anticipates the behavior of her future self and chooses z_1 strategically to maximize $\Pi(z_1, z_2(z_1))$. Thus, time-consistent output targeting yields the following production levels:

$$x_1^{TC} = \frac{\alpha(2 - \delta\psi + \delta^2\psi)}{4 + 2\delta\psi^2 + \delta^2\psi^2}, \quad x_2^{TC} = \frac{\alpha(4 + \delta\psi^2 + 2\psi)}{2(4 + 2\delta\psi^2 + \delta^2\psi^2)}, \tag{12}$$

Alternatively, under price targeting we obtain

$$p_1^{TC} = \frac{\alpha(2 - \delta\psi + \delta\psi^2 - \delta^2\psi - \delta^2\psi^2)}{4 + 2\delta\psi^2 - \delta^2\psi^2}, \quad p_2^{TC} = \frac{\alpha\delta(4 + 3\delta\psi^2 + 2\psi + \delta\psi^3)}{2(4 + 2\delta\psi^2 + \delta^2\psi^2)(1 + \delta\psi^2)}. \tag{13}$$

To demonstrate the differences across policy instruments, we compare the effects of price and output targeting on market outcomes. Table 1 provides information regarding the equilibrium prices and quantities, as well as the corresponding lifetime profits. The

Variables of interest	Value	Sign
$\Pi(p_1^{TC}, p_2^{TC}) - \Pi(x_1^{TC}, x_2^{TC})$	$\frac{\alpha^2\delta^2\psi^3(2+\psi-\delta\psi)}{4(1+\delta\psi^2)(4+2\delta\psi^2-\delta^2\psi^2)}$	> 0
$p_2^{TC} - p_2(x_1^{TC}, x_2^{TC})$	$-\frac{\alpha\delta^2\psi^2(2+\psi+\delta\psi^2)}{2(1+\delta\psi^2)(4+2\delta\psi^2-\delta^2\psi^2)}$	< 0
$p_1^{TC} - p_1(x_1^{TC}, x_2^{TC})$	$\frac{\alpha\delta^2\psi^3}{2(4+2\delta\psi^2-\delta^2\psi^2)}$	> 0
$x_2^{TC} - x_2(p_1^{TC}, p_2^{TC})$	$-\frac{\alpha\delta\psi^2(2+\psi)}{2(4+2\delta\psi^2-\delta^2\psi^2)}$	< 0
$x_1^{TC} - x_1(p_1^{TC}, p_2^{TC})$	$-\frac{\alpha\delta^2\psi^3(1+\psi)}{2(1+\delta\psi^2)(4+2\delta\psi^2-\delta^2\psi^2)}$	< 0

Table 1: Equilibrium outcomes under time-consistent price setting vs. output setting.

comparison shows that the equivalence of policy instruments unravels if firms are unable to precommit. Moreover, when $\alpha > 0, \psi \in (0, 1]$, and $\delta \in (0, 1]$, price targeting always yields a higher lifetime profit.

We gain further insight if we compare the time-consistent equilibria to the precommitment plan derived in the previous subsection. Table 2 shows that, regardless of the policy instrument, consumer expectations will force a time-consistent decision maker to set a period-1 price below her precommitment optimum p_1^{PC}, while the period-2 price will be above the precommitment optimum p_2^{PC}. However, under price targeting, the monopolist's intertemporal selves compete in terms of strategic substitutes. This allows the firm to maintain equilibrium policy levels closer to their precommitment values, resulting in higher profits.

Variables of interest	Value	Sign
$p_2^{PC} - p_2^{TC}$	$\frac{-\alpha\psi(8-4\delta\psi-4\delta^2\psi-6\delta^2\psi^2+10\delta\psi^2-3\delta^2\psi^3-\delta^3\psi^3+3\delta^2\psi^4-4\delta^3\psi^4+\delta^4\psi^4+\delta^4\psi^3)}{2(1+\delta\psi^2)(4+2\delta\psi^2-\delta^2\psi^2)(4+2\delta\psi^2-\delta^2\psi^2-\delta^2\psi^2)}$	< 0
$p_1^{PC} - p_1^{TC}$	$\frac{\alpha\psi^2(2+\delta\psi^2-\delta\psi-\delta^2\psi-\delta^2\psi^2)}{(4+2\delta\psi^2-\delta^2\psi^2)(4+2\delta\psi^2-\delta^2\psi^2-\delta^2\psi^2)}$	> 0
$p_2^{PC} - p_2(x_1^{TC}, x_2^{TC})$	$\frac{\alpha\,\psi\,(-8+4\,\delta\,\psi-4\,\delta^2\,\psi-2\,\delta\,\psi^2+2\,\delta^2\,\psi^2+\delta^2\,\psi^3-2\,\delta^3\,\psi^3+\delta^4\,\psi^3)}{2\,(-4-2\,\delta\,\psi^2+\psi^2+\delta^2\,\psi^2)\,(-4-2\,\delta\,\psi^2+\delta^2\,\psi^2)}$	< 0
$p_1^{PC} - p_1(x_1^{TC}, x_2^{TC})$	$\frac{-\alpha\,\psi^2\,(-4+2\,\delta\,\psi-2\,\delta^2\,\psi+2\,\delta^2\,\psi^2+\delta^2\,\psi^3-2\,\delta^3\,\psi^3-2\,\delta\,\psi^2+\delta^4\,\psi^3)}{2\,(-4-2\,\delta\,\psi^2+\psi^2+\delta^2\,\psi^2)\,(-4-2\,\delta\,\psi^2+\delta^2\,\psi^2)}$	> 0

Table 2: Equilibrium outcomes under precommitment vs. time-consistent price setting.

Figure 1 illustrates that the advantages of price targeting increase when ψ, δ are high. If the good is more addictive and agents are patient, the monopolist's time consistency problem worsens. This widens the discrepancy between price and output targeting.

Figure 1 here

To summarize, we find that in the case of precommitment, the monopolist's problem is identical to that of static price discrimination in interlinked markets. This, in turn, implies the equivalence of policy instruments. However, when the firm is unable to precommit, this equivalence no longer holds. In the next section, we show that this result holds also in an infinite-horizon framework.

3 The infinite-horizon model

In this section, we analyze profit maximization when the planning horizon is infinite. We devise a model which is amenable to changes in the state and choice variables: it can be formulated recursively under both output and price targeting. This setup differs from the two-period model in two aspects. On the demand side, we introduce overlapping generations of consumers. We assume that the monopolist can price discriminate between the young and old buyers. This hypothesis fits with recent empirical evidence on cigarette consumption[4]. The implied demand system enables us to study price and quantity regimes via a simple transformation of the state space. On the supply side, we assume that the monopolist incurs convex production costs. Thus, the marginal cost of serving the current young will depend on the output sold to the current old. These cost complementarities create a link between the contemporaneous markets.

We demonstrate that, under full precommitment, instrument selection is irrelevant. The analysis of time-consistent policies focuses on the Markov-perfect equilibrium (MPE) in differentiable strategies of the intra-personal game. As Driskill and McCafferty (2001) point out, this solution concept is particularly appealing since it is the limit of the finite game as the planning horizon expands to infinity. We compute the MPE pricing and output strategies and show that they imply differences in market conduct. This finding reinforces the non-equivalence result obtained in Section 2.

3.1 Setup

Consider two-period lived overlapping generations of consumers. As in Section 2, individuals derive utility from a numeraire good, m (when young), and a habit-forming good, x. Let x_t^y denote the addictive consumption of a person who is young in period t and x_{t+1}^o be the addictive consumption of that person when old in period $t+1$. The lifetime utility of the generation born in period t is given by:

$$\begin{aligned} U(m_t, x_t^y, x_{t+1}^o; \psi) &= m_t + v(x_t^o) + \delta u(x_{t+1}^o - \psi x_t^y) = \\ &= m_t + \alpha x_t^y - \frac{1}{2}(x_t^y)^2 + \delta\left(\alpha(x_{t+1}^o - \psi x_t^y) - \frac{1}{2}(x_{t+1}^o - \psi x_t^y)^2\right). \end{aligned} \tag{14}$$

[4]Weinberg (2005) matches data on brand level advertising with consumer level brand choice data and shows that young teenagers and adult smokers exhibit different degrees of sensitivity to prices. This implies that producers of habit-forming goods will benefit from price discrimination. Chaloupka and Pacula (2001) also suggest that teenagers respond differently than adults to cigarette prices for several reasons: young smokers 1) are likely to spend a greater share of their income on cigarettes; 2) are strongly affected by peer pressure; 3) will be less addicted than adults; and 4) are presumably more myopic.

Assume that the monopolist can price discriminate between the young and the old. Therefore, consumers face a budget constraint $m + p_t^y x_t^y + p_{t+1}^o x_{t+1}^o = w$, where p_t^y denotes the period$-t$ price the young generation faces and p_{t+1}^o is the period$-t+1$ price the old generation faces. The price of m is normalized to 1. Utility maximization yields the familiar inverse demand functions:

$$p_t^y = p_y(x_t^y, x_{t+1}^o) = \alpha - \delta\alpha\psi - \delta\psi^2 - x_t^y + \delta\psi^2 x_{t+1}^o, \quad p_{t+1}^o = p^o(x_t^y, x_{t+1}^o) = \delta\alpha + \delta\psi x_t^y - \delta x_{t+1}^o. \tag{15}$$

These correspond to the following demand functions:

$$x_t^y = x^y(p_t^y, p_{t+1}^o) = \alpha - p_t^y + \psi p_{t+1}^o, \quad x_{t+1}^o = x^o(p_t^y, p_{t+1}^o) = \alpha + \alpha\psi - \psi p_t^y - \frac{p_{t+1}^o(1+\delta\psi^2)}{\delta}. \tag{16}$$

On the production side, suppose that the monopolist has a convex cost function. Following Driskill and McCafferty (2001), we assume a quadratic operating cost:

$$C(x_t^y + x_t^o) = \frac{c[x_t^y + x_t^o]^2}{2}. \tag{17}$$

where $c > 0$ is a constant. From the firm's perspective, this cost structure generates a payoff link between the generations: the output sold in one market affects the marginal cost of serving the other.

Let $\{z_t^y, z_t^o\}$ denote the policy instrument (prices or output levels) adopted by the decision maker: $\{z_t^y, z_t^o\}_{t=1}^{\infty} = \{x_t^y, x_t^o\}_{t=1}^{\infty}$ or $\{z_t^y, z_t^o\}_{t=1}^{\infty} = \{p_t^y, p_t^o\}_{t=1}^{\infty}$. Let $\pi \in \{\widehat{\pi}, \widetilde{\pi}\}$ be the corresponding instantaneous payoff function. The above assumptions imply that, contingent on instrument selection, the period-t instantaneous profit of the monopolist is given by:

$$\widehat{\pi}(x_{t-1}^y, x_t^y, x_t^o, x_{t+1}^o) = p^y(x_t^y, x_{t+1}^o)x_t^y + p^o(x_{t-1}^y, x_t^o)x_t^o - C(x_t^y + x_t^o)$$

$$\widetilde{\pi}(p_{t-1}^y, p_t^y, p_t^o, p_{t+1}^o) = p_t^y x^y(p_t^y, p_{t+1}^o) + p_t^o x^o(p_{t-1}^y, p_t^o) - C(x_t^y(p_t^y, p_{t+1}^o) + x^o(p_{t-1}^y, p_t^o)). \tag{18}$$

3.2 Precommitment policies

First, suppose that in period 1 the monopolist can precommit to the entire lifetime sequence $\{z^y, z^o\}_{t=1}^{\infty}$ of future policies. That is, she solves:

$$\max_{\{z^y, z^o\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \delta^{t-1}\pi(z_{t-1}^y, z_t^y, z_t^o, z_{t+1}^o).$$

The optimal precommitment plan satisfies the following necessary conditions:

$$\frac{\partial\pi(z_{t-1}^y, z_t^y, z_t^o, z_{t+1}^o)}{\partial z_{t+1}^o} + \delta \frac{\partial\pi(z_{t-1}^y, z_t^y, z_t^o, z_{t+1}^o)}{\partial z_t^o} = 0, \ \frac{\partial\pi(z_{t-1}^y, z_t^y, z_t^o, z_{t+1}^o)}{\partial z_t^y} + \delta \frac{\partial\pi(z_{t-1}^y, z_t^y, z_t^o, z_{t+1}^o)}{\partial z_{t-1}^y} = 0.$$

Under output targeting, the steady state output levels sold to the young and the old are:

$$x_{ss}^y = \frac{\alpha(c - \delta c + 2\delta - \delta\psi c)}{2(2\delta + \delta c + c + c\delta\psi^2 + \delta\psi c)}, \quad x_{ss}^o = \frac{\alpha(\delta\psi c + 2\delta\psi + 2\delta + \delta c - c)}{2(2\delta + \delta c + c + c\delta\psi^2 + \delta\psi c)}.$$

Under price targeting, the steady state prices paid by the young and the old are:

$$p_{ss}^y = \frac{\alpha(c\delta\psi(\psi + 2 - \delta(1 - \psi^2 - 2\psi)) + \delta(3c + 2 - 2\delta\psi) + c)}{2(2\delta + \delta c + c + c\delta\psi^2 + \delta\psi c)}$$
$$p_{ss}^o = \frac{\delta\alpha(2\delta + \delta\psi c(2 + \psi) + c(\delta + 3 + \psi))}{2(2\delta + \delta c + c + c\delta\psi^2 + \delta\psi c)}.$$

Using (15) and (16), it is easy to verify that in the steady state output targeting is equivalent to price targeting:

$$\begin{aligned} p_{ss}^y &= p^y(x_{ss}^y, x_{ss}^o) \ , \quad p_{ss}^o = p^o(x_{ss}^y, x_{ss}^o) \\ x_{ss}^y &= x^y(p_{ss}^y, p_{ss}^o) \ , \quad x_{ss}^o = x^o(p_{ss}^y, p_{ss}^o) \ . \end{aligned}$$

3.3 Time-consistent policies

Next, we analyze time-consistent decision making in the absence of precommitment. We focus the analysis on Markovian strategies: the policies are restricted to be differentiable functions of the state z_{t-1}^y.

3.3.1 Characterization

Let the Markov-perfect strategy of the period $t+1$ monopolist in the young buyers' market be $z_{t+1}^y = f(z_t^y)$ and let her strategy in the old buyers' market be $z_{t+1}^o = g(z_t^y)$. Optimality and perfect foresight imply that the equilibrium policies solve the following Bellman equation:

$$V(z_y^{t-1}) = \max_{z_t^y, z_t^o} \{\pi(z_{t-1}^y, z_t^y, z_t^o, g(z_t^y)) + \delta V(z_t^y)\}. \tag{19}$$

Moreover, stationarity of MPE requires that the currently optimal strategies are precisely

$z_t^y = f(z_{t-1}^y)$, $z_t^o = g(z_{t-1}^y)$:

$$g(z_{t-1}^y) = \arg\max_{z_t^o}\{\pi(z_{t-1}^y, f(z_{t-1}^y), z_t^o, g(f(z_{t-1}^y))) + \delta V(f(z_{t-1}^y))\} \quad (20)$$

$$f(z_{t-1}^y) = \arg\max_{z_t^y}\{\pi(z_{t-1}^y, z_t^y, g(z_{t-1}^y), g(z_t^y)) + \delta V(z_t^y)\}. \quad (21)$$

Definition 1 *The Markov-perfect equilibrium of the intra-personal game is characterized by a value function* $V : \mathcal{R}_+ \rightarrow \mathcal{R}$ *which solves (19) and a pair of strategy functions* $f, g : \mathcal{R}_+ \rightarrow \mathcal{R}_+$ *which is a fixed point of the mapping defined by (20) and (21).*

To characterize the MPE strategies, we use dynamic programming. Differentiation with respect to z_t^o and z_t^y yields the first-order conditions:

$$\frac{\partial \pi(z_{t-1}^y, f(z_{t-1}^y), z_t^o, g(f(z_{t-1}^y)))}{\partial z_t^o} = 0 \quad (22)$$

$$\frac{\partial \pi(z_{t-1}^y, z_t^y, z_t^o, g(z_t^y))}{\partial z_t^y} + g'(z_t^y)\frac{\partial \pi(z_{t-1}^y, z_t^y, z_t^o, g(z_t^y))}{\partial z_t^y} + \delta V'(z_t^y) = 0. \quad (23)$$

The envelope condition is given by:

$$V'(z_{t-1}^y) = \frac{\partial \pi(z_{t-1}^y, z_t^y, z_t^o, g(z_t^y))}{\partial z_{t-1}^y}. \quad (24)$$

From (23) and (24), we obtain the following Euler equation:

$$\frac{\partial \pi(z_{t-1}^y, z_t^y, z_t^o, g(z_t^y))}{\partial z_t^y} + g'(z_t^y)\frac{\partial \pi(z_{t-1}^y, z_t^y, z_t^o, g(z_t^y))}{\partial z_t^y} + \delta\frac{\partial \pi(z_t^y, z_{t+1}^y, z_{t+1}^o, g(z_{t+1}^y))}{\partial z_t^y} = 0. \quad (25)$$

The term $g'(z_t^y)\dfrac{\partial \pi(.)}{\partial z_t^y}$ represents the "internal strategic effect". It accounts for the attempt of the current monopolist to strategically influence the behavior of her future self. This term disappears if the time-consistency problem is resolved.

Given the linear-quadratic structure, we conjecture linear MPE strategies:

$$x_{t+1}^y = a^y + b^y x_t^y, \quad x_{t+1}^o = a^o + b^o x_t^y, \quad p_{t+1}^y = d^y + e^y p_t^y, \quad p_{t+1}^o = d^o + e^o p_t^y.$$

We substitute these conjectures in (22) through (25) and use the method of undetermined coefficients to compute the equilibrium strategy parameters $a^y, a^o, b^y, b^o, d^y, d^o, e^y, e^o$.

3.3.2 Price targeting vs. Output targeting

The closed-form solution of the problem is rather intractable, so we illustrate our results using numerical examples.

Figure 2 to 6 here

Figures 2 through 6 show the differences between the two instruments in terms of profits, prices, and quantities as we vary the strength of habits and the discount factor. By comparing the Markov-perfect equilibria of the intra-personal quantity and pricing games, we find that the monopolist can attain higher steady-state profits by following a price strategy (see Figure 2).

Our numerical simulations confirm the results obtained in the two-period model. Under both output and price targeting, the MPE is characterized by prices that are below the precommitment optimum in the young buyers' market, but above the precommitment optimum in the old buyers' market. However, when the monopolist implements price targeting, she can sustain policies which are closer to the precommitment plan. The differences between price and output targeting are further compounded in the market comprised of old buyers. Also, note that when the discount factor and the degree of habit persistence are high, the monopolist's time consistency problem will worsen. This translates into larger discrepancies between the two regimes.

4 Conclusion

This paper studies the market conduct of a monopolist in a framework where consumer preferences display habit persistence. We use two simple models to demonstrate that time-consistent output and pricing strategies yield different equilibrium prices and allocations. To the best of our knowledge, this observation has gone formally untreated and empirically untested in models dealing with market power and habit persistence. Thus, our main contribution is to show that, in the absence of precommitment, the choice of strategies plays an important role in determining market outcomes.

The intuition behind our results is based on the different strategic properties of prices and quantities in the intra-personal game which determines the time-consistent equilibrium. If the policy variable is output, current and future quantities become strategic complements. In contrast, when the monopolist implements pricing policies, current and future prices are strategic substitutes. Consequently, price targeting mitigates intra-personal competition and allows the firm to attain higher profits. Since the intra-personal game is played by intertemporal agents of the same decision maker, they are likely to coordinate to the superior equilibrium. Thus, our result has important methodological implications: when studying monopolistic conduct in models with habit persistence, one should account for the strategic properties of market policies.

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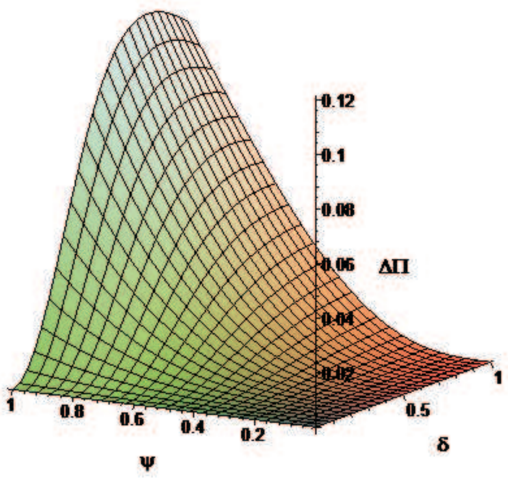


Figure 1: Plot of $\dfrac{\tilde{\Pi}(p_1^{TC}, p_2^{TC}) - \hat{\Pi}(x_1^{TC}, x_2^{TC})}{\hat{\Pi}(x_1^{TC}, x_2^{TC})}$ for ψ, $\delta \in [0, 1]$ and $\alpha = 2$.

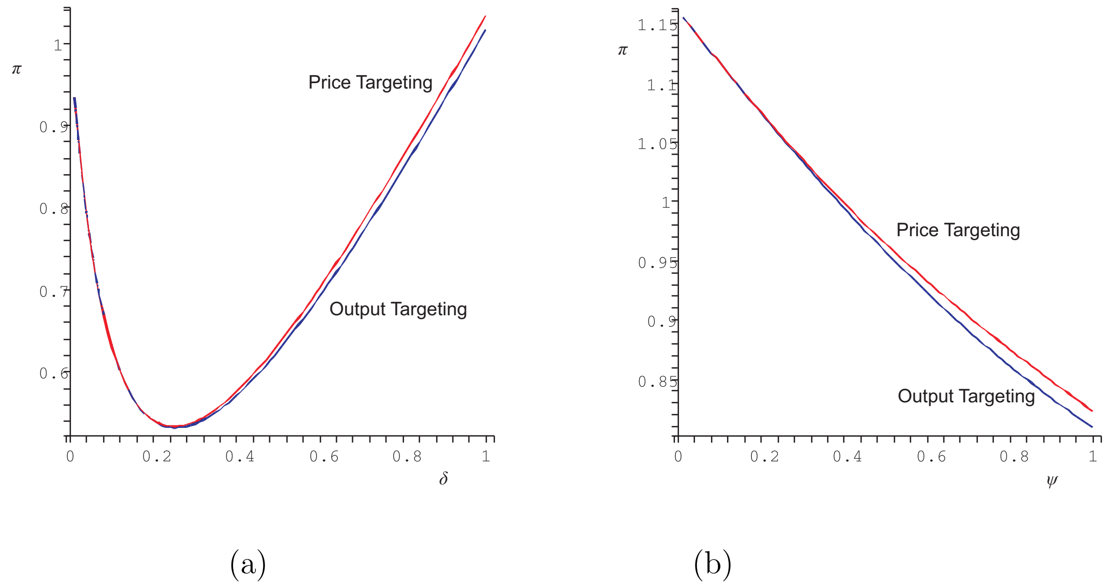
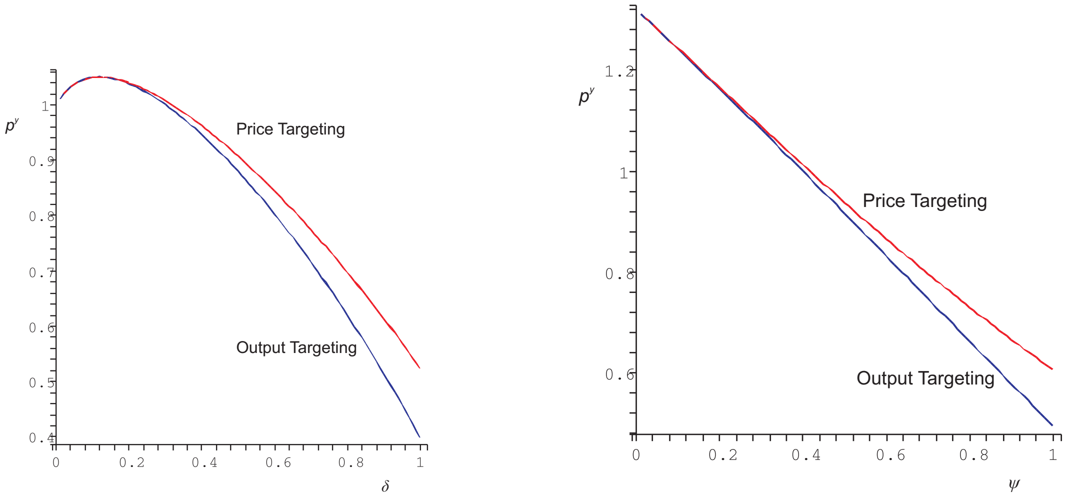
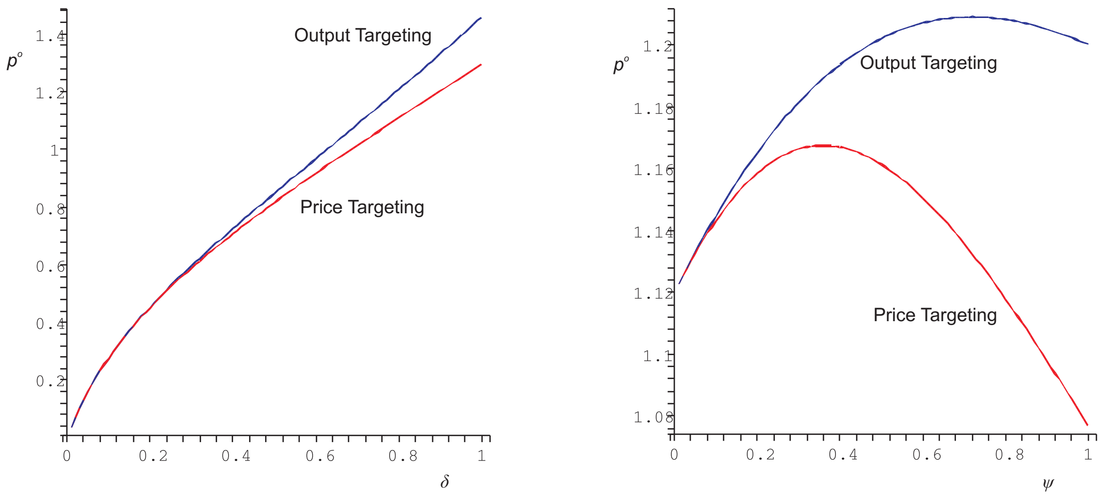


Figure 2: Case (a): $\widetilde{\pi}(p_{ss}^y, p_{ss}^o)$ and $\widehat{\pi}(x_{ss}^y, x_{ss}^o)$ for $\psi = 0.85$, as we vary $\delta \in [0, 1]$. Case (b): $\widetilde{\pi}(p_{ss}^y, p_{ss}^o)$ and $\widehat{\pi}(x_{ss}^y, x_{ss}^o)$ for $\delta = 0.8$ as one varies $\psi \in [0, 1]$. In both cases $c = 0.5$, $\alpha = 2$.



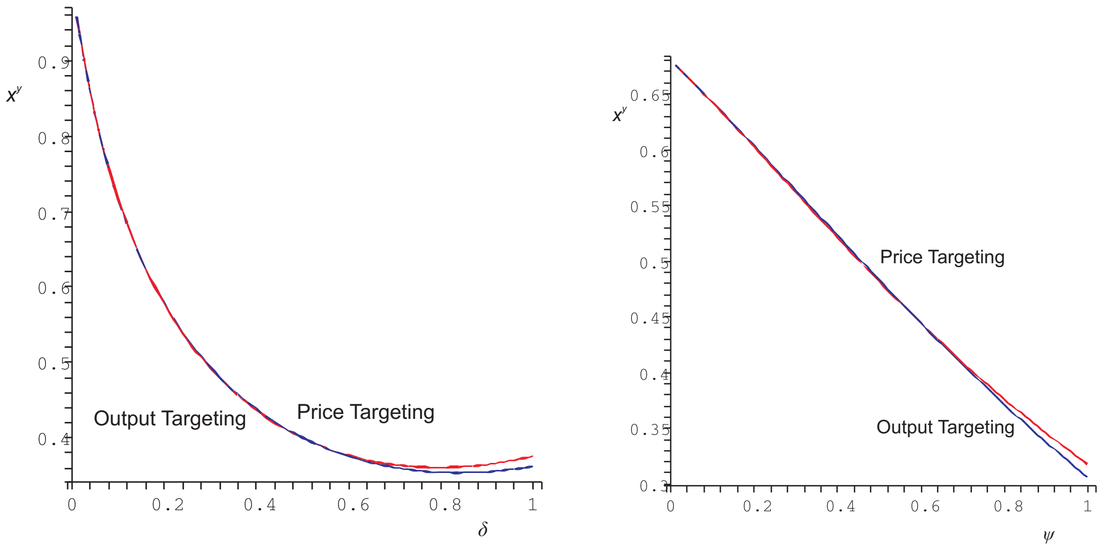
(a) (b)

Figure 3: Case (a): p^y_{ss} and $p^y(x^y_{ss}, x^o_{ss})$ for $\psi = 0.85$, as we vary $\delta \in [0, 1]$. Case (b): p^y_{ss} and $p^y(x^y_{ss}, x^o_{ss})$ for $\delta = 0.8$ as one varies $\psi \in [0, 1]$. In both cases $c = 0.5$, $\alpha = 2$.



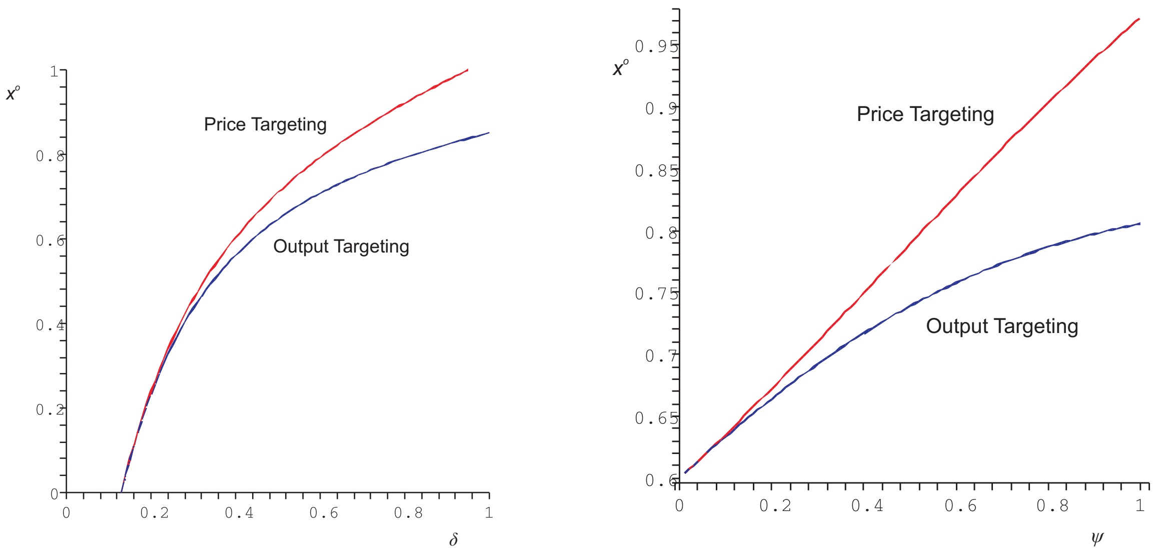
(a) (b)

Figure 4: Case (a): p^o_{ss} and $p^o(x^y_{ss}, x^o_{ss})$ for $\psi = 0.85$, as we vary $\delta \in [0, 1]$. Case (b): p^o_{ss} and $p^o(x^y_{ss}, x^o_{ss})$ for $\delta = 0.8$ as one varies $\psi \in [0, 1]$. In both cases $c = 0.5$, $\alpha = 2$.



(a) (b)

Figure 5: Case (a): $x^y(p^y_{ss}, p^o_{ss})$ and $x^y_{s.s.}$ for $\psi = 0.85$, as we vary $\delta \in [0, 1]$. Case (b): $x^y(p^y_{ss}, p^o_{ss})$ and x^y_{ss} for $\delta = 0.8$ as one varies $\psi \in [0, 1]$. In both cases $c = 0.5$, $\alpha = 2$.



(a) (b)

Figure 6: Case (a). Plot of $x^o(p^y_{ss}, p^o_{ss})$ and $x^o_{s.s.}$ for $\psi = 0.85$, as we vary $\delta \in [0, 1]$. Case (b). Plot of $x^o(p^y_{ss}, p^o_{ss})$ and $x^o_{s.s.}$ for $\delta = 0.8$ as one varies $\psi \in [0, 1]$. In both cases $c = 0.5$, $\alpha = 2$.