ESSAYS ON APPLIED MICROECONOMIC THEORY

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by

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Abstract

This thesis collects three essays in applied microeconomic theory.

Chapter 1 studies entry in a market where firms compete in shopping hours and prices. I explore the effect of shopping hours deregulation on social welfare. I show that an incumbent firm can strategically choose its opening hours to deter entry of a new firm, and that shopping hours deregulation can be harmful to consumers and social welfare.

Chapter 2 examines the implications of *prominence* when firms' R&D investment is endogenous and consumers search sequentially. In the benchmark case consumers visit a firm randomly while in the prominence case all consumers visit the prominent firm first. I find that the prominent firm is the most efficient firm. The non-prominent firm is the least efficient firm if R&D cost is high but invests more in R&D than with random search if R&D cost is low. Second, if the efficiency asymmetry is sufficiently low prices with prominence are lower than prices with random search. If the efficiency asymmetry is high prices with prominence are higher than prices with random search. If the efficiency asymmetry is not too low the prominent firm charges a lower price than the non-prominent firm, and the price with random search lies between those prices. Third, when a firm is prominent both consumer surplus and social welfare are higher than with random search.

Chapter 3 discusses whether taxes, subsidies and cash incentives are effective in reducing unhealthy food consumption, and which one is the most appropriate policy to tackle the obesity problem in the US and the UK. Cash incentives may be the most effective policy in reducing unhealthy food consumption, yet it can be the most costly one. Taxes are ineffective in reducing unhealthy food consumption. Subsidies have the best balance between effectiveness and monetary benefits to society.

Acknowledgements

Declaration

Chapter 1 has been published in the 2011 University of Leicester Discussion Paper Series in Economics. This chapter has been presented at the RES PhD Meeting 2012 (London), JEI 2011 (Valencia), EARIE Conference 2011 (Stockholm), NIE Doctoral Student Colloquium 2011 (Nottingham), and SMYE 2011 (Groningen).

Chapter 2 has been presented at the University of Leicester Internal Seminars, NIE Doctoral Students Colloquium 2012 (Nottingham), JEI 2012 (Murcia), EBES 2012 (Warsaw) and the CCP Seminar Series at University of East Anglia.

Chapter 3 is a joint work with Javier Rivas. This chapter has been published in the 2012 University of Leicester Discussion Paper Series in Economics. This chapter has been presented at the University of Leicester Internal Seminars and ECHE 2012 (Zurich).

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1.1 Introduction

Shopping hours regulation has been widely debated in many European countries. In the past decades, countries such as Sweden and the U.K. extended their opening hours in the retail industry. Recently, Italy has introduced opening hours deregulation allowing shops, coffees and restaurants to set their own opening hours.[1] Others countries, e.g. Austria, Denmark, Finland and Norway, are more sceptical and maintain restriction on shopping hours.

One of the main concerns of shopping hours liberalisation is how deregulation may affect the structure and competitiveness of the retail industry. Early empirical studies[2] focused on the effect of longer opening hours on the market share of stores of different sizes. Morrison and Newman (1983) show that shopping hours deregulation redistributes sales from small to large stores. Tanguay et al. (1995) find that the prices charged by large stores can increase when shopping hours are deregulated.[3] On the theoretical side, recent studies focused on the explanations of the possibility of higher prices after opening hours deregulation. Inderst and Irmen

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[1] The New York Times, January 06, 2012.

[2] Kay and Morris (1987) show evidence for the UK that inefficient equilibria where competitive pressures would induce excessive opening at times when high costs would be incurred (e.g. Sundays) does not arise.

[3] They use Canadian data to study whether the Canadian shopping hours deregulation in 1990 increases price at large stores with long opening hours.

(2005)[4] and Shy and Stenbacka (2008)[5] show that retail prices can increase because deregulation may lead to opening hour differentiation, which segments the market and softens price competition. Wenzel (2011)[6] studies the effect of shopping hours deregulation on competition between large retail chains and smaller, independent competitors. He shows that an independent retailer can gain higher profits after deregulation provided that their efficiency disadvantage relative to retail chains is sufficiently small. The possible effect of shopping hours deregulation on the social welfare has also been discussed. Shy and Stenbacka (2008) find that shopping hours deregulation increases social welfare. Similarly, Wenzel (2011) finds that shopping hours deregulation increases both consumer surplus and total welfare.

In this chapter I analyse the effect of shopping hours deregulation on entry, an aspect which has been overlooked by the previous literature. More specifically, I focus on the possibility that incumbent firms strategically expand their opening hours to deter entry. I show entry deterrence through opening hours is actually possible in a market where firms can compete in shopping hours and prices. I also study the implications for the social desirability of shopping hours deregulation.

My framework builds on Inderst and Irmen (2005) and Shy and Stenbacka (2008). I consider a model of oligopolistic competition with product differentiation in two dimensions: space and time. I adapt the Hotelling (1929) model of spatial differentiation to study a market where firms compete for consumers with different preferences in their shopping hours. The interaction between the incumbent and a potential entrant is analysed in a three-stage game. In the first stage, the incumbent chooses its opening hours. In the second stage, after observing the decision taken by the incumbent, the potential entrant decides whether to enter the market and, in the entry case, its opening hours. Finally, in stage three, incumbent and entrant compete in prices if entry occurred at the second stage, otherwise the incumbent monopolises the market. The structure of the game captures the idea that

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[4]They study why prices may rise after shopping hours deregulation.

[5]They focus on the relationship between equilibrium business hour configuration and flexibility of consumers to advance or postpone their shopping.

[6]He extends the previous theoretical papers to the case of firms' efficiency asymmetries.

the incumbent's decision about its opening hours can affect entry and the industry structure.

The results of this chapter are twofold. First, entry deterrence is possible: in a sizeable parameter region of the model, the incumbent expands opening hours to deter entry relative to the optimal level in the absence of entry threat. Second, shopping hours deregulation can be harmful to consumers and social welfare.

I explore the effect of shopping hours deregulation on entry and its welfare implications from two possible regulatory regimes. The first one is motivated by the fact that shopping hours regulation is frequently combined with entry restrictions (e.g. number of licenses to operate in the market). In this case, I consider a regulated situation where only the incumbent is active in the market due to entry restrictions. Moreover, the incumbent faces shopping hours regulation. The regulated situation is compared with a liberalised market; there is no entry restrictions and shopping hours are deregulated. In the second regulatory regime entry is not regulated (e.g. no restriction in the number of licenses). In this case I discuss a regulated situation where both the incumbent and entrant compete in the market with shopping hours regulation. I compare this situation with a liberalised market where shopping hours are deregulated.

This chapter contributes to two literatures. It first contributes to the literature on oligopolistic competition with multi-dimensional product differentiation. I study entry in a three-stage model of duopolistic competition with two dimensions of product differentiation: space and shopping time.[7] The second contribution is to the literature of entry deterrence. I show that an incumbent firm can use opening hours as a strategic commitment to deter entry. This result relates to the pre-

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[7]The most well known models of two-dimensional product differentiation are from Economides (1989), Neven and Thisse (1990), and Tabuchi (1994). As pointed out by Inderst and Irmen (2005), the two-dimensional product differentiation they study has two major novelties. First, they consider a piecewise uniform distribution of consumer preferences with respect to shopping hours: the mass of consumers uniformly distributed over the day time interval is greater than the mass of consumers uniformly distributed over the night time interval. This captures the empirical fact that most consumers prefer to go shopping during the day. Second, they consider a firm's product variant characterised by a point in the geographical space and an interval in the time space. This chapter follows a similar approach.

emption strategies in one-dimension product differentiation models studied by Bonanno (1987) and Schmalansee (1978), where pre-emption occurs through strategic brand proliferation: incumbents expand their products lines to leave no profitable niche to entrants. Longer opening hours can also be interpreted as time product differentiation which creates barriers to entry in the sense of Bain (1956).

The remaining of the chapter is organised as follow. Subsection 1.2 describes the model. Subsection 1.3.1 solves the final stage of the game. Subsection 1.3.2 analyses the equilibrium shopping hours and entry decisions. Section 1.4 studies the effects of shopping hours deregulation on entry in terms of consumer surplus and social welfare. Finally, subsection 1.5 concludes. All proofs are relegated to the Appendix.

1.2 The Model

I use a model of duopolistic competition with product differentiation in two dimensions: space and time. For this purpose, I add a shopping time dimension to the standard Hotelling (1929) model of spatial differentiation. The location of firms is exogenous. This assumption simplifies the analysis without losing generality, as the focus of this chapter is on entry in a market with shopping hours and price competition.

1.2.1 Consumers

Consumers differ in two dimensions: i) distance to firms' location, and ii) preferred shopping time. Along the first dimension, consumers are uniformly distributed along a unit line, $l \in [0, 1]$. Each of them has unit demand and faces a transportation cost of $\alpha > 0$ per unit of distance from a firm. Along the time dimension consumers are of two types. The first type prefers shopping during the day, D, and the other

prefers shopping during the night, N.[8] [9] At each spatial location, a fraction λ of consumers is of type D, while a fraction $1 - \lambda$ is of type N, where $\lambda \in \left(\frac{1}{2}, 1\right]$. Hence, the mass of consumers who prefer to shop during the day is greater than the mass of those who prefer to shop at night.

Each consumer is then identified by a pair of coordinates (l, t), where $l \in [0, 1]$ is the consumer's spatial location on the unit line, and $t = \{D, N\}$ denotes her time preference for shopping hours. The utility consumer (l, t) derives from buying the good from a firm located at l_i with opening hours t_i is given by

$$U_{l,t}(l_i, t_i) = V - p_i - \alpha \left| l - l_i \right| - \beta(t, t_i). \tag{1.1}$$

$V \in \mathbb{R}_+$ is the consumers' value for the product and $p_i \in \mathbb{R}_+$ is the price charged by firm i. The term $\alpha \left| l - l_i \right|$ is the transportation cost, and $\beta(t, t_i)$ is the disutility of shopping at a time which differs from the consumer's preferred one. In equation (1.1),

$$\beta(t, t_i) = \begin{cases} \beta & \text{if } t \neq t_i, \\ 0 & \text{if } t = t_i. \end{cases}$$

If $t \neq t_i$, the consumer suffers a cost β because the firm is not open at her preferred time. If $t = t_i$, no cost is incurred since the consumer can buy the product at her preferred time.

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[8]Inderst and Irmen (2005) and Shy and Stenbacka (2008) used the circular model of Salop (1979) to represent shopping time differentiation. In those models each point in the unit circle represents an ideal shopping time for a continuum of potential shoppers. My model simplifies consumers' ideal time to a discrete preference for shopping time.

[9]For example, when consumers go shopping to a grocery store, some of them may prefer to shop during day because they can find more variety of fresh products (vegetables, fruits, fish, etc.), while others prefer shopping during the night because of working hours restrictions.

1.2.2 Firms

I consider two firms, $i = I, E$, as possible sellers of the product. The incumbent I is already in the market located at $l_I = 0$. E is a potential entrant. To enter the market and locate at $l_E = 1$, the entrant must pay a fixed entry cost $F > 0$.

Incumbent's decision on opening hours is a discrete choice between two options: i) open only during the day, D; and ii) open all day, A. Entrant decides whether to enter the market or stay out, and upon entry its preferred opening hours among the same alternatives as the incumbent's. To compact the notation of the entrant's choice, I posit $t_E = \{D, A, Out\}$, where Out means that the entrant decides not enter the market.[10]

For simplicity, marginal production costs are normalised to zero. Firms however incur in a fixed operating cost which depends on the opening time: $k > 0$ is incurred to operate a firm during the day and the cost of operating the firm all day is μk, with $\mu \in (1, 2]$. The later implies that firms may gain increasing returns to scale in the opening time.

The interaction between the incumbent and the potential entrant is analysed in a three-stage game:

- At *stage 1*, the incumbent chooses its opening hours $t_I = \{D, A\}$.

- At *stage 2* and after observing t_I, the entrant chooses $t_E = \{Out, D, A\}$.

- At *stage 3* and after having observed incumbent and entrant decisions, firms simultaneously choose their prices if the entrant has entered the market. In the case the entrant chooses to stay out of the market the incumbent behaves as a monopolist. I rule out price discrimination.

I assume that retailers can commit to their opening hours choices.[11] Indeed, if a firm chooses longer opening hours he commits to keep on opening longer hours. This is because, once the firm chooses to open all day, if he decides to change its opening

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[10] The qualitative feature of the equilibrium do not change if firms' opening time decisions are between open only during the day, open only during the night or open all day.

[11] The same assumption is made by Inderst and Irmen (2005) and Shy and Stenbacka (2008).

hours (by opening only during the day), the firm would have a cost: renegotiate labour and insurance contracts, and invest in advertising the new opening time.

Figure 1.1 shows the extensive form of the game. In the next section I look for the subgame perfect equilibrium (SPE) in pure strategies of the game.

Figure 1.1: The Entry Game
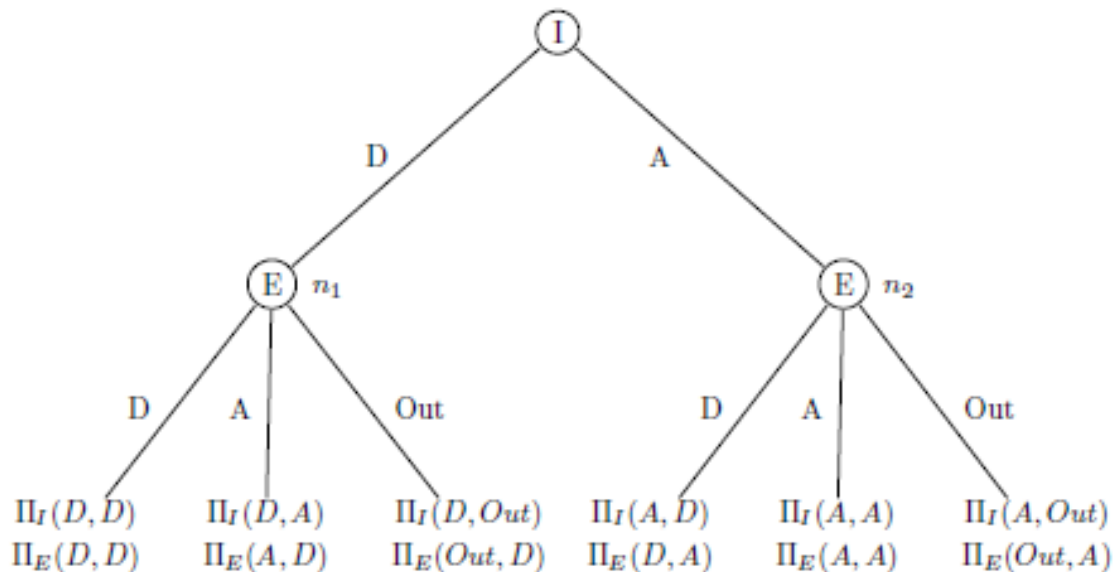
1.3 Analysis

In this subsection, I first analyse the equilibrium of the last stage of the game (Subsection 1.3.1). Then I discuss opening hours and entry decisions (Subsection 1.3.2).

1.3.1 Final stage

Consider first the case where the entrant has entered the market at stage two. Given the incumbent and entrant opening hours decisions, firms compete in prices at stage three.

Denote with p_I and p_E the prices charged by the incumbent and entrant, respec-

tively. Assuming the market is fully covered, firms' demand functions are:

$$D_I(p_I, p_E) = \lambda \min\{l_D; 1\} + (1 - \lambda) \min\{l_N; 1\} \tag{1.2}$$

$$D_E(p_E, p_I) = \lambda \min\{(1 - l_D); 1\} + (1 - \lambda) \min\{(1 - l_N); 1\}, \tag{1.3}$$

where l_D and l_N are the marginal consumers with day and night shopping time preferences, respectively. The marginal consumers depend on firms' opening time, t_I and t_E. Using (1.1), a consumer is indifferent between shopping at I or E if

$$V - p_I - \alpha |l - l_I| - \beta(t, t_I) = V - p_E - \alpha |l - l_E| - \beta(t, t_E). \tag{1.4}$$

Then, l_D and l_N are derived from (1.4). There are two relevant cases. First, if both firms are open and closed at the same shopping time ($t_I = t_E = D$, or $t_I = t_E = A$), then

$$l_D = l_N = \frac{1}{2} + \frac{p_E - p_I}{2\alpha}.$$

In this case, only transportation costs and prices affect the consumers' decision.

The second case is when one firm opens all day and the other firm opens only during the day. Suppose $t_I = A$ and $t_E = D$. Then, the marginal consumers are

$$l_D = \frac{1}{2} + \frac{p_E - p_I}{2\alpha}$$
$$l_N = \frac{1}{2} + \frac{p_E - p_I + \beta}{2\alpha}.$$

The case where $t_I = D$ and $t_E = A$ is symmetric.

Firm i's operating profits are

$$\Pi_i(p_i, p_j) = p_i D_i(p_i, p_j) - K,$$

where $i = I, E$ and $K = k, \mu k$. So, given opening hours decisions (t_i, t_j), equilibrium

prices are given by $p_i^* \in \arg\max_{p_i} \Pi_i(p_i, p_j^*)$. Equilibrium prices and profits are shown in Table 1.1.

<div align="center">Table 1.1: Equilibrium Prices and Profits</div>

t_I	t_E	p_I^*	p_E^*	Π_I^*	Π_E^*
D	D	α	α	$\frac{\alpha}{2} - k$	$\frac{\alpha}{2} - k - F$
D	A	$\alpha - \frac{\beta(1-\lambda)}{3}$	$\alpha + \frac{\beta(1-\lambda)}{3}$	$\frac{(3\alpha - \beta(1-\lambda))^2}{18\alpha} - k$	$\frac{(3\alpha + \beta(1-\lambda))^2}{18\alpha} - \mu k - F$
D	Out	$\frac{V - \beta(1-\lambda)}{2}$	-	$\frac{(V - \beta(1-\lambda))^2}{4\alpha} - k$	0
A	D	$\alpha + \frac{\beta(1-\lambda)}{3}$	$\alpha - \frac{\beta(1-\lambda)}{3}$	$\frac{(3\alpha + \beta(1-\lambda))^2}{18\alpha} - \mu k$	$\frac{(3\alpha - \beta(1-\lambda))^2}{18\alpha} - k - F$
A	A	α	α	$\frac{\alpha}{2} - \mu k$	$\frac{\alpha}{2} - \mu k - F$
A	Out	$\frac{V}{2}$	-	$\frac{V^2}{4\alpha} - \mu k$	0

Let us now suppose that the entrant stays out of the market at the second stage of the game ($t_E = Out$). In this situation the incumbent behaves as a monopolist. Suppose it charges p_I^m, then the demand function is given by

$$D_I(p_I^m) = \lambda \, min\{l_D^m; 1\} + (1 - \lambda) \, min\{l_N^m; 1\} \tag{1.5}$$

where m denotes the monopoly case, l_D and l_N are the consumers with day and night preference who are indifferent between shopping at I or not buying the good.[12]

The location of the marginal consumers depends on the opening hours chosen by the incumbent and are derived from[13]

$$V - p_I - \alpha \, |l - l_I| - \beta(t, t_I) = 0.$$

Assume the market is not fully covered. If $t_I = D$, the marginal consumers are $l_D = \frac{V - p_I}{\alpha}$ and $l_N = \frac{V - p_I - \beta}{\alpha}$. If $t_I = A$, the marginal consumer is $l_D = l_N = \frac{V - p_I}{\alpha}$.

The incumbents' profits are $\Pi_I(p_I) = p_I D_I(p_I) - K$, where $K = k, \mu k$. So, without entry and given the incumbent's opening hours decision, t_I, equilibrium prices is given by $p_I^* \in \arg\max_{p_I} \Pi_I(p_I)$. The prices and incumbents' profits are shown in Table 1.1.

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[12]Notice that the marginal consumers with entry are derived from different expressions than the marginal consumers without entry. In order to keep notation simple I use l_D and l_N for both cases.

[13]If the consumer does not buy the good she gets zero utility.

1.3.2 Equilibrium Shopping Hours and Entry

Entrants' optimal choice

Entrant's profits are denoted by $\Pi_E(t_E, t_I)$. The following Lemma characterises the optimal choice of E as a function of the incumbent's decision at the first stage.

Lemma 1. *Entrants' optimal choice is as follows.*
If $t_I = D$:

    (a) If $\Delta k > b_0$ and $\frac{\alpha}{2} - k > F$, then $t_E^* = D$;

    (b) If $\Delta k < b_0$ and $\frac{\alpha}{2} + b_0 - \mu k > F$, then $t_E^* = A$;

    (c) If $\frac{\alpha}{2} - k < F$ and $\frac{\alpha}{2} + b_0 - \mu k < F$, then $t_E^* = Out$;

If $t_I = A$:

    (d) If $\Delta k > b_1$ and $\frac{\alpha}{2} - b_1 - k > F$, then $t_E^* = D$;

    (e) If $\Delta k < b_1$ and $\frac{\alpha}{2} - \mu k > F$, then $t_E^* = A$;

    (f) If $\frac{\alpha}{2} - b_1 - k < F$ and $\frac{\alpha}{2} - \mu k < F$, then $t_E^* = Out$.

Where $\Delta = (\mu - 1)$, $b_0 = \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$, and $b_1 = \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$.

Lemma 1 *(a)* and *(d)* state that the entrant chooses to open only during the day when the additional cost of operating all day (Δk) is relatively high, holding constant all other parameters, and given $t_I = D$ or $t_I = A$, respectively. Conversely, Lemma 1 *(b)* and *(e)* state that it is more convenient to open all day when the additional cost of operating all day is low. Finally, Lemma 1 *(c)* and *(f)* state the conditions for the entrant to remain out of the industry when the incumbent opens only during the day or opens all day, respectively.

Incumbents' optimal choice

Let us now analyse the incumbents' optimal choice at the first stage of the game. According to the game tree in Figure 1.1, there are six possible histories of the

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three-stage game: four with entry, and two without entry. The possibles SPE are described in the following result.

Proposition 1. *The industry equilibrium is as follows.*

If $\beta(1 - \lambda) < 6\alpha$ (C1):

(a) If $\Delta k > b_0$ and $\frac{\alpha}{2} - k > F$, then $(t_I^*, t_E^*)=(D, D)$;

(b) If $\Delta k < b_1$, and $\frac{\alpha}{2} - \mu k > F$, then $(t_I^*, t_E^*)=(A, A)$;

(c) If $b_1 < \Delta k < b_0$, $\Delta k < b2$ and $\frac{\alpha}{2} - b_1 - k > F$, then $(t_I^*, t_E^*)=(A, D)$.

If $\beta(1 - \lambda) > 6\alpha$ (C2):

(d) If $\Delta k > b_0$ and $\frac{\alpha}{2} - k > F$, then $(t_I^*, t_E^*)=(D, D)$;

(e) If $\Delta k < b_2$ and $\frac{\alpha}{2} - b_1 - k > F$, then $(t_I^*, t_E^*)=(A, D)$;

(f) If $b_2 < \Delta k < b_0$ and $\frac{\alpha}{2} + b_0 - \mu k > F$, then $(t_I^*, t_E^*)=(D, A)$.

If $F > \hat{F} = max\{F_1, F_2, F_3\}$:

(g) If $\frac{1}{2} + b_3 \Delta k > \frac{V}{\beta(1-\lambda)}$, then $(t_I^*, t_E^*)=(D, Out)$;

(h) If $\frac{1}{2} + b_3 \Delta k < \frac{V}{\beta(1-\lambda)}$, then $(t_I^*, t_E^*)=(A, Out)$.

(i) If $\Delta k > b_0$, $\frac{\alpha}{2} - k > F$, $\frac{\alpha}{2} - b_1 - k < F$, $\frac{\alpha}{2} - \mu k < F$, and $\Delta k < \frac{V^2}{4\alpha} - \frac{\alpha}{2}$,
then $(t_I^*, t_E^*)=(A, Out)$.

Where $b_2 = \frac{2\beta(1-\lambda)}{3}$, $b_3 = \frac{2\alpha}{\beta^2(1-\lambda)^2}$, $F_1 = \frac{\alpha}{2} - k$, $F_2 = \frac{\alpha}{2} + b_0 - \mu k$, and $F_3 = \frac{\alpha}{2} - b_1 - k$.

Notice that $b_0 > b_1$, and $b_0 \gtrless b_2$. Thus, in order to define the regions for each possible duopoly outcome we need a parameter condition. If condition C1 holds $b_1 < b_0 < b_2$, which is the first part of Proposition 1. On the contrary, if condition C2 holds $b_1 < b_2 < b_0$, which is the second part of Proposition 1. The last inequality in Proposition 1 *(a) - (f)* is the require condition for the entrant to make profits. In order to illustrate the industry equilibrium when there is entry in the market,

Figure 1.2: Duopoly Equilibrium under C1

(A,A)	(A,D)	(D,D)

0   b_1 b_0 b_2 Δk
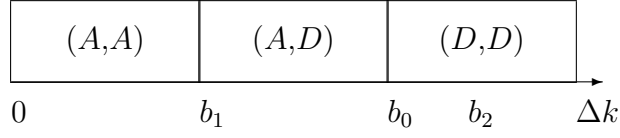
Figure 1.3: Duopoly Equilibrium under C2

(A,D)	(D,A)	(D,D)

0   b_2 b_0 Δk
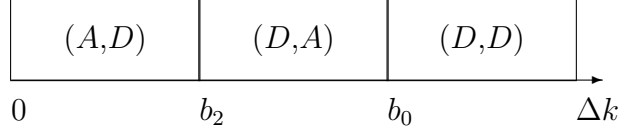
Figures 1.2 and 1.3 show the region for each possible outcome under C1 and C2, respectively.

The symmetric duopoly (D, D), in Proposition 1 *(a)* and *(d)*, arises when the additional cost of operating all day is sufficiently high ($\Delta k > b_0$). On the other hand, a symmetric duopoly (A, A), in Proposition 1 *(b)*, arises when the additional cost of operating all day is low ($\Delta k < b_1$). However, a duopoly with longer opening hours is not possible under C2. This is because C2 implies that $b_1 < 0$, which is not inside the parameter region for $\Delta k > 0$. This is the reason why in Figure 1.2 we observe the outcome (A, A), while in Figure 1.3 this outcome is not feasible.

Noteworthy is that both asymmetric duopoly cases (A, D) and (D, A), in Proposition 1 *(e)* and *(f)*, are possible under C2, while the asymmetric case (A, D) is only possible under C1 (Proposition 1 *(c)*). The reason is as follows. For the parameter range $b_1 < \Delta k < b_0$ the entrant's optimal strategy is to open only during the day if the incumbent opens all day and the entrant opens all day if the incumbent opens only during the day. Given the entrant's strategy, the incumbent chooses to open only during the day or all day depending on whether $\Delta k \gtrless b_2$. C1 implies that $b_0 < b_2$, therefore opening only during the day is not an optimal choice for the incumbent under C1.

Proposition 1 *(g)* and *(h)* state the industry equilibrium when E chooses $t_E = Out$ at the second stage no matter what I has decided at the first stage because

$\Pi_E \left(Out, t_i \right) > \Pi_E \left(t_E, t_i \right)$, for $t_E \neq Out$. In this case, the incumbent behaves as an unconstrained monopolist and chooses its opening hours according to $t_I^* \in \arg\max\limits_{t_I} \Pi_I \left(t_I, Out \right)$. This situation is possible when the fixed entry cost is sufficiently high $(F > \hat{F})$, then, entry is blockaded.[14]

Finally, the first and second inequalities in Proposition 1 *(i)* state that the entrant enters the market with day opening hours if the incumbent opens only during the day, and the third and forth inequalities in Proposition 1 *(i)* state that the entrant stays out of the market if the incumbent opens all day. The last inequality in Proposition 1 *(i)* state that, given entrant's optimal choice, the incumbent prefers to open all day.

1.4 Policy Discussion

This subsection examines the potential effects of shopping hours deregulation on entry and social welfare, W, defined as the sum of consumer surplus, CS, and industry profits. For this purpose, I consider two alternative regulatory regimes. First, I analyse a regulated situation where only the incumbent is active in the market (Subsection 1.4.1). Second, I discuss a regulated scenario where both the incumbent and entrant are active in the market (Subsection 1.4.2).

The analysis is as follows. Under each regulatory regime I identify the equilibrium outcome that characterises the regulated scenario (benchmark) and the possible industry equilibrium outcomes that may arise without regulation. Afterwards, I compare the regulated scenario with the possible deregulated outcomes in terms of consumer surplus and social welfare.

So far I showed that without restrictions in firms' opening hours there are five possible equilibrium outcomes. Two of them arise when there is no entry: a monopoly open only during the day and a monopoly open all day. Denote these

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[14]F_1 and F_2 are the fixed entry costs that assure no profits to the entrant by choosing $t_E = D$ and $t_E = A$ if the incumbent chooses $t = D$, respectively. F_3 is the fixed entry cost that assures no profits to the entrant by choosing $t_E = D$ if the incumbent chooses $t_I = A$. Notice that the fixed entry cost that assures no profits to the entrant by choosing $t_E = A$ if the incumbent chooses $t_I = A$ is $F_4 = \frac{\alpha}{2} - \mu k$. However, the assumption $\mu \in (1, 2]$ implies $F_3 > F_4$.

outcomes as (D, Out) and (A, Out), respectively. If the entrant enters the market the possible outcomes depend on whether C1 or C2 hold. Under C1 three possible outcomes arise: two symmetric duopolist and an asymmetric duopolist. Denote the symmetric duopolist as (D, D) and (A, A), and the asymmetric duopolist as (A, D). Under C2 three possible outcomes arise: a symmetric duopoly (D, D) and two asymmetric duopolist. In the latter case, in addition to the outcome (A, D), denote the other asymmetric duopoly as (D, A). Table 1.2 shows the consumer surplus and social welfare under each equilibrium outcome.[15]

Table 1.2: Social Welfare

Equilibrium	Consumer Surplus	Social Welfare
(D, Out)	$\frac{V^2}{8\alpha} + \frac{\beta(1-\lambda)V}{4\alpha} - \frac{\beta(1-\lambda)(8\alpha+\beta(3+\lambda))}{8\alpha}$	$\frac{3V^2}{8\alpha} - \frac{\beta(1-\lambda)(2V+16\alpha+\beta(1+3\lambda))}{8\alpha} - k$
(A, Out)	$\frac{V^2}{8\alpha}$	$\frac{3V^2}{8\alpha} - \mu k$
(D, D)	$V - \frac{5}{4}\alpha - \beta(1-\lambda)$	$V - \frac{\alpha}{4} - \beta(1-\lambda) - 2k - F$
(A, A)	$V - \frac{5}{4}\alpha$	$V - \frac{\alpha}{4} - 2\mu k - F$
(A, D) or (D, A)	$V - \frac{5}{4}\alpha + \frac{\beta^2(4\lambda^2+\lambda-5)}{36\alpha}$	$V - \frac{\alpha}{4} + \frac{\beta^2(8\lambda^2-7\lambda-1)}{36\alpha} - (1+\mu)k - F$

1.4.1 Entry and Shopping Hours Deregulation (Regime I)

This case is motivated by the fact that shopping hours regulation is frequently combined with entry restrictions. In the grocery retail market, for example, the authority may regulate the time firms can be opened and also the number of licenses to operate in the market (legal barrier to enter in the market). The authority may want to promote entry in the market by conferring additional licenses to new firms and, simultaneously, liberalise shopping times, so firms are free to choose their opening hours. Is it possible that market liberalisation may harm consumers and social welfare?

In order to address this question, let us suppose that in the regulated scenario only the incumbent is active in the market due to entry restrictions, and that opening hours are regulated so the incumbent is allowed to open only during the day. Notice

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[15]Details of the consumer surplus expressions in each case are in the Appendix.

that (D, Out) may also arise due to prohibitive entry cost, $F > \hat{F}$, given regulated shopping hours. The consumer surplus and social welfare are equivalent in both situations; (D, Out) due to entry restrictions or prohibitive entry cost. Thus, the regulated situation (benchmark) is equivalent to the equilibrium $(t_I^*, t_E^*) = (D, Out)$.

Market liberalisation consists of granting a new license to another firm, so the potential entrant may enter the market and compete with the incumbent. Moreover, shopping hours are deregulated, so firms are free to choose their opening hours. Thus, in the deregulated scenario the possible SPE are: (A, Out), (D, D), (A, D), and (A, A) if C1 holds or (D, A) if C2 holds.[16]

Before comparing the regulated scenario with the possible deregulated outcomes, it is important to make the distinction of the possible sources of the outcome (A, Out). Indeed, a monopoly with longer opening hours may arise due to: i) high entry cost $(F > \hat{F})$; ii) entry is ruled out by the regulator (legal barrier to enter); or iii) entry deterrence strategy. The latter is defined as follows.

Definition 1. *Entry deterrence through opening hours occurs if:*

(i) *The entrant stays out of the market if the incumbent opens all day but enters the market with day opening hours if the incumbent opens only during the day; and*

(ii) *The incumbent opens only during the day if there is no threat of entry but expands its opening hours to all day if there is an entry threat.*

Notice that an entry deterrence strategy combines alternative incumbents' strategies in different parameter regions according to the fixed entry cost. To be more precise, Definition 1 *(ii)* states that the incumbent's opening hours decision would be different whether there is entry threat or not: incumbent chooses $t_I = D$ if entry is blockaded $(F > \hat{F})$, while the incumbent chooses $t_I = A$ if there is an effective entry threat $(F < \hat{F})$.

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[16]The equilibrium (D, Out) is also possible in the deregulated scenario. However, if that is the case both regulated and deregulated outcomes are equivalent, therefore market liberalisation has no effect on the industry equilibrium. This is not an interesting case to discuss.

According to Definition 1 we have the following lemma.

Lemma 2. *Entry deterrence through opening hours is possible if:*

(a) $\frac{\alpha}{2} - b_1 - k < F$, $\frac{\alpha}{2} - \mu k < F$;

(b) $\Delta k > b_0$, $\frac{\alpha}{2} - k > F$;

(c) $F > \hat{F}$, $\frac{1}{2} + b_3 \Delta k > \frac{V}{\beta(1-\lambda)}$;

(d) $\Delta k < \frac{V^2}{4\alpha} - \frac{\alpha}{2}$, $\Delta k > \frac{\beta(1-\lambda)V}{2\alpha} - \frac{\beta^2(1-\lambda)^2}{4\alpha}$.

Lemma 2 shows that an entry deterrence strategy can occur in a market with shopping hours and price competition, the first main result of this chapter.

Entry deterrence through opening hours is detected by comparing a situation where F is high such that entry is blockaded with a situation where F is low. Thus, the equilibrium is (A, Out), however E would enter if $t_I = D$. Denote this outcome as ED (A, Out). Let discuss in more detail the equilibrium conditions for entry deterrence.

The inequalities in Lemma 2 *(a)* imply that the entrant chooses to stay out of the market when the incumbent opens all day because the fixed entry cost is high. The inequalities in Lemma 2 *(b)* imply that the entrant makes profits by opening only during the day if the incumbent opens only during the day as well. Lemma 2 *(c)* implies that the incumbent chooses day opening hours if there is no entry threat (F is high). The first inequality in Lemma 2 *(d)* means that the incumbent's best response to entrant's strategy is to open all day because $\Pi_I(A, Out) > \Pi_I(D, D)$. Hence, *entry deterrence is desirable* by the incumbent. The second inequality in Lemma 2 *(d)* means that *opening longer hours is caused by the threat of entry*: the incumbent would open only during the day if there is no entry threat and expands its opening hours if there is an entry threat. This inequality arises from the comparison $\Pi_I(A, Out) < \Pi_I(D, Out)$, where $\Pi_I(A, Out)$ is the monopoly profit with all day opening hours when there is an effective entry threat, $F < \hat{F}$, and $\Pi_I(D, Out)$ is the

unconstrained monopoly profit with day opening hours due to $F > \hat{F}$ (blockaded entry).[17]

To better illustrate that ED (A, Out) is possible, Figure 1.4 shows an example of the parameter region where entry deterrence through opening hours is feasible. Figure 1.4 considers the following parameter specification: $\lambda = \frac{2}{3}$, $V = 2$, $k = \frac{1}{4}$ and $F = \frac{1}{5}$. Panel (a) assumes the parameter that measures the degree of returns to scale in opening hours is $\mu = \frac{5}{4}$, while in panel (b) $\mu = 2$. The figure depicts spatial product differentiation α on the horizontal axis, and time product differentiation β on the vertical axis. Entry deterrence is more likely with a higher μ because if the incumbent does not expand its opening hours and let the entrant to enter the market then a duopoly (D,D) is more likely to arise. Consider point A in Figure 1.4. If the increasing return to scale in opening hours is high (panel (a)) both firms open all day in point A. However, if there are no increasing return to scale in opening longer hours (panel (b)) and the incumbent does not deter entry, then both firms open only during the day in point A.

Figure 1.4: Entry Deterrence

(a) $\mu = \frac{5}{4}$ (b) $\mu = 2$
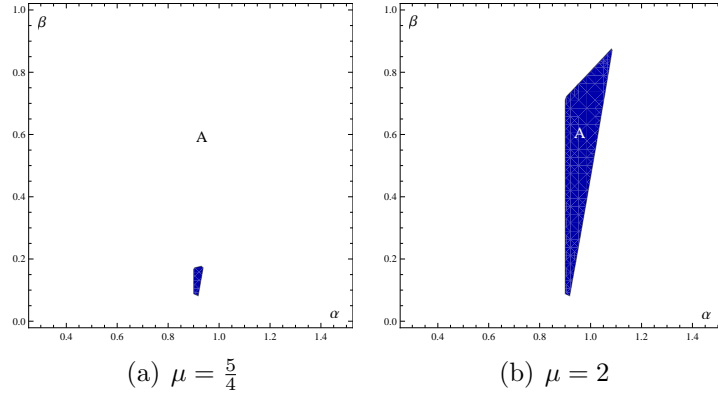
I analyse the effect of market liberalisation (allow the possibility of entry and shopping hours deregulation) by comparing the benchmark, (D, Out), with each of the possible equilibrium under deregulation: ED (A, Out), (D, D), (A, A), (A, D) and (D, A).

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[17]This is the distinction pointed by Salop (1979) between natural (or innocent) barriers to entry and strategic barriers to entry. With the latter, the incumbent behaves strategically in order to protect the market.

Comparison (D, Out) vs ED (A, Out)

Let compare first the benchmark with ED (A, Out). Recall that in the latter case the industry equilibrium arise due to the strategic behaviour of the incumbent when there is entry threat (entry is not blockaded). As a consequence, in this case shopping hours deregulation allows the incumbent to behave strategically to deter entry.

If deregulation leads to ED (A, Out), consumers can be better off or worse off with regulation. This depend on whether $2V \gtrless 8\alpha + \beta(3 + \lambda)$.

According to the previous inequality, consumers are better off with regulation if $2V > 8\alpha + \beta(3 + \lambda)$. In this comparison there are two opposing effects on consumer surplus: on the one hand, consumers suffer no disutility in time (*time effect*) with ED (A, Out) and, on the other hand, consumers have to pay higher prices with ED (A, Out) due to time flexibility (*price time-flexibility effect*). If the later effect dominates the former one, then consumers are better off with regulation.

The social welfare with regulation is higher than with deregulation if $\Delta k > \frac{\beta(1-\lambda)}{8\alpha}(2V + 16\alpha + \beta(1 + 3\lambda))$. This implies that when the additional operating cost of longer opening hours is high, the society is better off with (D, Out) than with ED (A, Out). The opposite result emerges when the additional operating cost of longer opening hours is low, hence society is worse off with (D, Out).

Comparison (D, Out) vs (A, A)

I compare now the benchmark with (A, A). Notice that in this case I compare a monopoly equilibrium where the incumbent firm (located at the zero extreme of the unit line) optimally serves only part of the market with a duopoly equilibrium (one firm is located at each extreme of the unit line) that serves the entirely market. Thus, we need to consider the condition such that the demand in equilibrium with (D, Out) is less than the unit mass of consumers (entire market), that is $D_I^* = \frac{V - \beta(1-\lambda)}{2\alpha} < 1$.

If deregulation leads to a symmetric equilibrium with longer opening hours, (A,

A), consumers are better off with regulation if the following two conditions hold:

$$\frac{V^2}{2\alpha} + \frac{\beta(1-\lambda)}{\alpha}V + 5\alpha \quad > \quad 4V + \frac{\beta(1-\lambda)(8\alpha + \beta(3+\lambda))}{2\alpha}$$

$$V \quad < \quad 2\alpha + \beta(1-\lambda)$$

The first inequality arises from the comparison of the consumer surplus with regulation versus the consumer surplus without regulation (Table 1.2).

The second inequality arises from the partial-served monopoly market condition just discussed. This inequality implies that the price charged by the monopolist with day opening hours, $p_I = \frac{V-\beta(1-\lambda)}{2}$, must be lower than the price charged under the duopoly with symmetric opening hours, $p_I = p_E = \alpha$. This effect is due to the fact that the entrant locates at the opposite extreme of the incumbent's location, which increases the willingness to pay for those consumers that are located closer to the entrant firm (these consumers face lower transportation cost relative to the monopoly situation). As a consequence, the duopolistic firm's demand functions are steeper than the monopoly demand function and lead to a higher equilibrium price than the monopoly, despite the countervailing standard effect of price competition (more firms in a market lead to lower prices).

The previous result has been pointed out by Chen and Riordan (2008). They show that a symmetric duopoly price can be higher with respect to the single-product monopoly price if price sensitivity effect (duopolist's demand curve is steeper relative to the monopolist's) is higher than the market share effect (at the monopoly price, a duopoly firm sells to fewer consumers than the monopolist). Chen and Riordan result is due to the fact that with a single-product monopoly consumers can buy one variety while with a duopoly consumers can choose between two varieties. Furthermore, the adverse price effect can be strong enough that aggregate consumer welfare goes down even though consumers are better served and the market expands under duopoly.

In our comparison between the regulated and deregulated scenarios we have three

possible effects. First, consumers pay a higher price in the liberalised market (*price-increasing competition effect*). This is due to the comparison between the monopoly and duopoly outcomes. Second, type N consumers have no disutility in time (*time effect*) with deregulation, which is a positive effect on consumer surplus. Third, consumers have to pay a higher price with (A, A) than with (D, Out) caused by time flexibility (*price time-flexibility effect*), which is a negative effect on consumer surplus. Thus, if price competition and price time-flexibility effects dominate time effect consumers are worse off with deregulation.

The social welfare with regulation is higher than with deregulation if $(2\mu - 1)k + F + \frac{3V^2}{8\alpha} - V + \frac{\alpha}{4} > \frac{\beta(1-\lambda)}{8\alpha}(2V + 16\alpha + \beta(1 + 3\lambda))$, otherwise welfare is higher with deregulation. The former is the case for a high operating cost, k, given other parameters.

Comparison (D, Out) vs (D, D)

Let compare the benchmark with (D, D). If deregulation leads to a symmetric equilibrium (D, D), consumers are better off with regulation if the following two conditions hold:

$$\frac{V^2}{8\alpha} - V + \frac{\beta(1-\lambda)}{4\alpha}V + \frac{5}{4}\alpha + \beta^2(\lambda^2 + 2\lambda - 3) > 0$$

$$V < 2\alpha + \beta(1 - \lambda)$$

The first inequality arises from the comparison of the consumer surplus with regulation versus the consumer surplus without regulation. The second inequality arises from the partial-served monopoly market condition discussed in the previous case.

Notice that in this case there are neither time nor price time-flexibility effects (consumers can buy the product only during the day both with regulation and deregulation). Thus, only price competition effect matters. The partial-served monopoly

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market condition (second inequality) implies that the price charged by the monopolist with day opening hours, $p_I = \frac{V - \beta(1-\lambda)}{2}$, must be lower than the price charged under the duopoly with symmetric opening hours, $p_I = p_E = \alpha$. This suggests that deregulation can harm consumers only if the duopoly charges a higher price than the monopoly (price-increasing competition effect).

The social welfare with regulation is higher than with deregulation if $\frac{3V^2}{8\alpha} + \frac{\alpha}{4} + \beta(1-\lambda) + k + F > V + \frac{\beta(1-\lambda)(2V + 16\alpha + \beta(1+3\lambda)))}{8\alpha}$, otherwise welfare is higher with deregulation.

Comparison (D, Out) vs (A, D)

I compare now the benchmark with (A, D). If deregulation leads to an asymmetric equilibrium (A, D), consumers are better off with regulation if the following two conditions hold:

$$\frac{V^2}{8\alpha} + \frac{5}{4}\alpha + \frac{\beta(1-\lambda)}{4\alpha}V > V + \beta(1-\lambda) - \frac{\beta^2(\lambda^2 + 16\lambda - 17)}{72\alpha}$$

$$V < 2\alpha + \beta(1-\lambda)$$

These inequalities suggest that when the spatial product differentiation is high and the disutility in time for night shoppers is relatively low consumers are worse off with a liberalised market.

In this case, with regulation there is a negative time effect and a positive price time-flexibility effect. The former is because type N consumers cannot buy the product at their preferred time with regulation, and the latter is because those consumers who buy from the incumbent pay less with regulation, $p_I = \frac{V - \beta(1-\lambda)}{2} < \alpha$ (partial-served monopoly market condition), than the price they would have to pay from the incumbent with deregulation, $p_I = \alpha + \frac{\beta(1-\lambda)}{3}$. Thus, if price time-flexibility effect dominates time effect consumers are better off with regulation.

The social welfare with regulation is higher than with deregulation if $\frac{3V^2}{8\alpha} + \frac{\alpha}{4} +$

$\mu k + F > V + \frac{\beta(1-\lambda)(2V+16\alpha+\beta(1+3\lambda))}{8\alpha} + \frac{\beta^2(8\lambda^2-7-1)}{36\alpha}$, otherwise welfare is higher with deregulation.

Finally, the comparison between $(D,\ Out)$ vs $(D,\ A)$ is equivalent to the comparison between $(D,\ Out)$ vs $(A,\ D)$.

The following lemma summarises the previous discussion.

Lemma 3. *Suppose in a regulated market the incumbent is the only active firm and only day opening hours is allowed. If market is liberalised (no entry restrictions and shopping hours are deregulated), then:*

(a) *Consumers can be better off with regulation if market liberalisation leads to entry deterrence, a symmetric duopoly with longer opening hours, or an asymmetric duopoly where one firm opens longer hours and the other firm opens only during the day;*

(b) *Social welfare is higher with regulation if, other things equal, the additional operating cost of longer opening hours is sufficiently high.*

1.4.2   Shopping Hours Deregulation (Regime II)

This subsection focuses on market liberalisation only through shopping hours deregulation. To make the interpretation easier, it is convenient to discuss deregulated and regulated scenarios in the following way. Let start considering a situation where the market is completely liberalised; there are neither entry nor opening hours restrictions. Suppose that the authority imposes regulation in opening hours, so firms are allowed to open only during the day. Is it possible that shopping hours regulation benefit consumers and social welfare?

I focus the discussion on the situation where the liberalised market can be characterised by the following equilibrium: a symmetric duopoly with longer opening hours, $(A,\ A)$, and an asymmetric duopoly, either $(A,\ D)$ or $(D,\ A)$.[18] Moreover, I

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[18]In the liberalised market, equilibrium outcomes where entry is blockaded, $(D,\ Out)$ and $(A,\ Out)$, or $(A,\ Out)$ due to an entry deterrence strategy, are also possible. Nevertheless, under this policy regime the main focus is on the effect of shopping hours deregulation where entry is not prohibitive either because of fixed entry cost or because entry is rule out by the regulator.

analyse the situation where both the incumbent and entrant are active in the market under shopping hours regulation. Thus, the regulated situation can be represented by the equilibrium outcome where both incumbent and entrant compete with day opening hours, (D, D).

Under this regime, I compare the regulated scenario (D, D) with two possible liberalised outcomes: (A, A) and (A, D).[19] Notice that in this policy regime I compare a duopoly regulated market with a duopoly deregulated market. Thus, there is no price competition effect (the number of firms is the same with and without regulation).

Comparison (D, D) vs (A, A)

Let compare the first possible liberalised outcome, (A, A), with (D, D). If without shopping hours restrictions the outcome is a symmetric duopoly with longer opening hours, consumers are better off under deregulation. In this case, there is no *price time-flexibility effect* because equilibrium prices with a duopoly (A, A) are equivalent to equilibrium prices with a duopoly (D, D), therefore consumers pay the same price in both regulated and deregulated scenarios. On the other hand, deregulation poses a positive *time effect* on consumer surplus due to longer opening hours.

The social welfare with regulation is higher than with deregulation if $2\Delta k > \beta(1 - \lambda)$, otherwise welfare is higher with deregulation. This implies that society is better off with regulation (deregulation) when the additional operating cost of longer opening hours is sufficiently high (low) in terms of the disutility in time for type N consumers.

Comparison (D, D) vs (A, D)

Let compare the other possible liberalised outcome, (A, D), with (D, D). If without shopping hours restrictions the outcome is an asymmetric duopoly (A, D), consumers can be better off or worse off with regulation. This depend on whether

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[19]Given that consumer surplus and social welfare are the same for both (A, D) and (D, A), I only discuss (A, D).

$-\frac{\beta(4\lambda^2+\lambda-5)}{36\alpha} \gtrless (1-\lambda)$.

The latter inequality implies that consumers are better off with regulation if:

$$\left|\frac{\beta(4\lambda^2+\lambda-5)}{36\alpha}\right| > (1-\lambda).$$

This implies that consumers are better off with regulation if the mass of type N consumers is low and the disutility in time for these consumers is high. In this case, with regulation time effect is negative and price time-flexibility effect is positive. The former is because type N consumers cannot buy the product at their preferred time with regulation, and the latter is because those consumers who buy from the incumbent pay less with regulation, $p_I = \alpha$, than the price they would have to pay from the incumbent with deregulation, $p_I = \alpha + \frac{\beta(1-\lambda)}{3}$. Thus, if price time-flexibility effect dominates time effect consumers are better off with regulation.

The social welfare with regulation is higher than with deregulation if $\Delta k > \beta(1-\lambda) + \frac{\beta^2(8\lambda^2-7\lambda-1)}{36\alpha}$, otherwise welfare is higher under the deregulated situation.

The following lemma summarises the previous discussion.

Lemma 4. *Suppose in a regulated market both the incumbent and entrant are active and both firms are allowed to open only during the day. If market is liberalised (shopping hours are deregulated), then:*

(a) *Consumers can be better off with regulation if market liberalisation leads to an asymmetric duopoly where one firm opens longer hours and the other firm opens only during the day;*

(b) *Social welfare is higher with regulation if, other things equal, the additional operating cost of longer opening hours is sufficiently high.*

1.4.3 Implications

Upon analysis the results suggest that market deregulation can be harmless or harmful to consumer surplus and social welfare. In particular, deregulation can negatively

affect consumers depending on the equilibrium outcome that characterises a liberalised market. On the one hand, if entry and shopping hours are regulated and market liberalisation deregulates both entry and shopping hours (Regime I), consumers can be better off with regulation if market liberalisation leads to entry deterrence, a symmetric duopoly with longer opening hours or an asymmetric duopoly. On the other hand, if entry is not regulated and market liberalisation deregulates shopping hours only (Regime II), consumers can be better off with regulation if market liberalisation leads an asymmetric duopoly.

Shopping hours regulation poses a time effect and a price time-flexibility effect on consumer welfare. The former is negative because type N consumers cannot buy the product at their preferred time with regulation, and price time-flexibility is positive because those consumers who buy from the incumbent (entrant) pay less with regulation than the price they would have to pay from the incumbent (entrant) with deregulation. Thus, if price time-flexibility effect dominates time effect consumers are better off with regulation.

Regarding social welfare, if the additional operating cost of longer opening hours (in terms of the disutility for the night preference consumers) is relatively high, society is worse off with a deregulated market. Conversely, society is better off with shopping hours deregulation for low additional operating cost of longer opening hours.

The findings and implications in this framework contribute to the literature on shopping hours deregulation. Shy and Stenbacka (2008) show, in a model with symmetric retailers and no entry, that shopping hours deregulation increases social welfare, therefore there is no justification for restrictions on opening hours. Similarly, Wenzel (2011) shows, in a model with asymmetric retailers and no entry, that shopping hours deregulation increases both consumer surplus and social welfare. I show here the conditions where market deregulation enhances or reduces consumer surplus when entry into the market is possible. Moreover, this setting allows us to discuss a broader policy implications. In fact, I study the interaction of an entry

promotion policy (remove legal barrier to entry) and shopping hours deregulation, which is a new aspect in this literature.

1.5   Conclusion

This chapter explores whether an incumbent firm can use opening hours strategically to deter entry into the market. I also study the effect of shopping hours deregulation on entry and its welfare implications. I use a model of oligopolistic competition with product differentiation in two dimensions; space and time. I analyse the interaction between an incumbent and a potential entrant in a three-stage competition with respect to shopping hours and prices.

The results of this chapter are twofold. First, entry deterrence is possible: in a sizeable parameter region of the model, the incumbent expands opening hours to deter entry. Second, shopping hours deregulation can be harmful to consumers and social welfare.

I explore the effect of shopping hours deregulation on entry and its welfare implications from two possible regulatory regimes. First, I consider a regulated scenario with entry and shopping hours restrictions. Second, I study a regulated scenario with no entry restrictions and where shopping hours are regulated. Under each regulatory regime I characterised the regulated and deregulated scenarios. Afterwards, I compare both scenarios in terms of consumer surplus and social welfare.

This chapter contributes to the literature of competition in multi-dimensional product differentiation and the public debate on shopping hours regulation. This framework allows to study how shopping hours deregulation affect the incentives of incumbent firms to use opening hours as a strategic variable when there is an entry threat. This chapter also contributes to the entry deterrence literature. I showed that entry deterrence is possible when firms compete in shopping hours and prices: an incumbent firm uses opening hours as a strategic commitment. This result relates to the pre-emption strategies in one-dimension product differentiation

models studied by Bonanno (1987) and Schmalansee (1978), where pre-emption occurs through strategic brand proliferation. Longer opening hours can also be interpreted as time product differentiation which creates barriers to entry in Bain's (1956) sense.

Chapter 2

R&D and Prominence with Consumer Search

2.1 Introduction

In many industries, lead companies spend large amounts of money on research and development (R&D) in order to increase their expected profits and gain market share. In 2009, market leaders in the pharmaceutical and biotechnology industry invested 59% of the R&D, top companies in the software industry invested 71% of the R&D, and top leaders in the automobile and parts sector invested 65% of the R&D, respectively in each sector.[1] [2] In these types of markets, consumers are initially imperfectly informed about the products available and must search until they find out a satisfactory product. Assuming that consumers search randomly among alternative options is not realistic; especially when consumers are looking for a particular attribute in a product. For example, when a consumer wants to buy a car and the security of the car is one of the main attributes she is looking for, then it is highly probable she will search for car brands that invest highly in car security.[3]

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[1]The 2010 R&D scoreboard: the top 1,000 UK and 1,000 global companies by R&D investment, Department for Innovation Business & Skills, UK.

[2]The calculations consider the 1,000 companies most active in R&D globally. I consider the ten most active firms in each sector as top companies.

[3]Another example is when a consumer wants to buy a television, then it is most probably she will consider to search first those brands that are well recognised in the market for having a high image quality.

A firm that is visited early in the consumer search process will have an advantage relative to a firm which is visited later. In this sense, a firm which is likely to be sampled first by consumers has a *prominent* position in the market.

The aim of this chapter is to analyse the effects of prominence when firms' R&D investment is endogenous in a market where consumers search sequentially for a product. In particular, whether prominent firms invest more in R&D than non-prominent firms and how investment decisions affect price competition, industry profits and consumer welfare. I assume that prominence is exogenous, as in Armstrong et al. (2009), henceforth referred to as AVZ.

I consider a model of oligopolistic competition with product differentiation in a search market. Two firms choose their R&D levels to reduce their unit production costs (cost-reduction investment stage). Then, both firms set their prices. Consumers are initially imperfectly informed about the deals available in the market so they search among firms to make a purchase. In the benchmark case, consumers' choices are viewed *ex ante* symmetrically, then consumers search randomly between firms (random search case). In the prominence case, following AVZ, all consumers start visiting the prominent firm first and, if consumers are not satisfied with the initial offer, they will go on to search the non-prominent firm. The structure of the model captures the effects of cost-reduction investment on price competition in a market with sequential search.

When comparing random search with prominence I find three main results. First, the prominent firm is the most efficient firm (chooses the highest R&D level). The effect of prominence on the prominent firm is clear; this firm has the incentive to invest more in R&D irrespective of the R&D cost. However, the effect of prominence on the non-prominent firm depends on the R&D cost. If R&D cost is high, the non-prominent is the least efficient firm (chooses the lowest R&D level). When R&D is costly the efficiency difference between prominent and non-prominent firms is large, and the non-prominent firm has less incentive to invest than when consumers search randomly. If R&D cost is low the non-prominent firm invest more in R&D than with

random search. When R&D is costless the efficiency difference between prominent and non-prominent firms is small, and the non-prominent firm has the incentive to invest more than when consumers search randomly.

Second, the effect of prominence on prices depends on firms' efficiency asymmetry. If the efficiency asymmetry is very small, prices with prominence are lower than prices with random search. If the efficiency asymmetry is large, prices with prominence are higher than with random search. The intermediate case is when the efficiency asymmetry is not too low; the prominent firm charges the lowest price and the non-prominent firm charges the highest price compare to the price with random search.

The previous findings can be explained in terms of two driving effects. The first one is that the prominent firm is able to charge a lower price because is the most efficient firm: the prominent firm invests more in R&D and has a lower marginal cost compare to the non-prominent rival and the random search case (lower price due to cost-efficiency). On the other hand, the prominent firm is able to charge a higher price because the non-prominent rival charges a higher price: when a firm is prominent, its non-prominent rival charges a higher price because invest less in R&D than the prominent firm (the marginal cost of the non-prominent firm is higher than the marginal cost of the prominent firm). Hence, the prominent firm faces less price competition pressure and is able to charge a higher price (higher price due to strategic effect). Which effect dominates depends on firms' efficiency asymmetry. If the efficiency asymmetry is very small the cost-efficiency effect dominates the strategic effect. Thus, prices with prominence are lower than prices with random search. If the efficiency asymmetry is high the strategic effect dominates the cost-efficiency effect, therefore prices with prominence are higher than prices with random search. We have the intermediate case if the efficiency asymmetry is not sufficiently low.

Third, when a firm is prominent both consumer surplus and social welfare are higher than with random search. The intuition for this result is as follows. The

gain in consumer surplus from those who buy immediately from the prominent firm (without searching the non-prominent firm) offsets the loss in consumer surplus from other consumers (consumers who buy from the rival firm and consumers who go back to the first visited firm). This suggests that the number of search and total search costs with prominence are lower than with random search.

From the comparative static analysis of the prominence case noteworthy results are the following. First, when searching becomes costly, the prominent firm invests more in R&D and the non-prominent firm invests less in R&D. This result can be explained by two opposite effects: market share and business stealing. The first one means that, for a given search cost, a higher demand (market share) implies a greater incentive to increase unit profits through cost-reduction investment. The second means that, for a given search cost, a firm has the incentive to invest in cost-reduction because, by doing so, it can steal a rival's business. For the prominent firm the market share effect is stronger and the business stealing effect is weaker, while for the non-prominent firm the market share effect is weaker and the business stealing effect is stronger. In this framework, the market share effect dominates the business stealing effect. Finally, prices are non-monotonic in search costs. In the case of the prominent firm, when search costs move away from zero, this firm has the incentive to charge more due to the positive effect of search costs in its demand function. However, when search costs are sufficiently high, the prominent firm finds it is convenient to reduce its price in order to attract those consumers who visit the non-prominent rival. In the case of the non-prominent firm, when search costs move away from zero, this firm reduces its price in order to keep those consumers who visit the non-prominent firm and, thus, avoid consumers going back to the prominent firm. Nevertheless, when search costs are sufficiently high, the non-prominent firm charges a higher price because the non-prominent firm expects that those consumers who visit its store found a very bad offer in the prominent store (market power effect).

The remaining of the chapter is organised as follow. I introduce a framework of

duopolistic competition with product differentiation and consumer search in Subsection 2.2. In Subsection 2.3 I solve the model. The main focus of this chapter is to analyse the effect of prominence when firms' R&D investment is endogenous. For this, I consider as a benchmark the case where consumers follow a random sequential process (Subsection 2.3.1). Then I study the prominence case by assuming that all consumers start searching from the prominent firm first. Afterwards, I compare the prominence equilibrium with the random search equilibrium (Subsection 2.3.2). I also study the comparative statics for the prominence case in terms of search costs. In Subsection 2.4 I present the conclusions. All proofs are relegated to the Appendix.

2.1.1 Related literature

The contribution of this chapter to the literature is twofold. On the one hand, it contributes to the economic analysis of R&D investment by studying the strategic interaction between R&D decisions and prices in a market where consumers search sequentially for a product. On the other hand, this work contributes to the economic analysis of the implications of prominence by modeling *endogenous firms' efficiency*. This is done by allowing firms to choose their marginal production costs through cost-reduction investment, and then compete in prices when consumers start searching the prominent firm first.

My work is closely related to AVZ and Haan and Moraga-Gonzales (2011), the later henceforth referred to as HM. AVZ examine the effects of prominence on price competition when firms have no quality differences (symmetric case). They show that the prominent firm charges a lower price than its non-prominent rivals, and the price with random search lies between those prices. In this case prominence increases industry profit but reduces consumer surplus and welfare.[4] They extend their model to the case of *exogenous* product qualities differences (asymmetric case).[5]

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[4]The non-prominent firms are induced to charge higher prices and the resulted non-uniform prices across firms lead to less efficient match between consumers and products. Moreover, prominence reduces total output.

[5]They introduce exogenous asymmetries between firms by setting that each firm has linear demand and quality is indexed by the vertical intercept of this demand.

They find that a firm with a higher average quality charges a higher price, and the highest-quality firm has the greatest incentive to become prominent.[6] They show that making prominent the highest quality firm increases both industry profit and consumer surplus, and thus total welfare, compared to a situation with no prominence.

The main different results between AVZ and this chapter are the following. First, with endogenous firms' efficiency I find that broader equilibrium prices relationship with prominence arise. Indeed, the price relationship between prominent, non-prominent and random search in AVZ is one (the intermediate) of the three possible cases in my framework. Second, I find that industry profits with prominence can be higher or lower than with random search. Third, consumer surplus with prominence is higher than with random search. This result is different from the symmetric case in AVZ and the same result from the heterogeneous quality case in AVZ. However, the result in this chapter has a different explanation from AVZ. In AVZ prominence is a signal of high quality (and high price), so prominence guides consumers toward better and better value products. Hence, the prominent firm offers the highest quality and charges the highest price. In my framework, the prominent firm always charge less than the non-prominent rival, and the gain in consumer surplus from those who buy immediately from the prominent firm offsets the loss in consumer surplus from other consumers. This suggests that the number of search and total search costs in equilibrium with prominence are lower than with random search.

HM study the effects of search costs when consumers first visit the firm whose advertising is most salient and firms are equally efficient in generating saliency (symmetric case). They extend the basic model to study a duopoly where one firm is *exogenously* more efficient in generating saliency (asymmetric case). In the latter case they show that the firm with more efficient advertising technology advertises more, charges lower prices and obtains higher profits than a less efficient rival. Furthermore, when advertising cost asymmetries increase, consumer surplus falls and

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[6]AVZ study the exogenous asymmetric case with an infinite number of firms and symmetric costs.

aggregate profits rise. I show, on the contrary, that when efficiency asymmetry increases consumer surplus with prominence is higher than with random search. My model differ from HM in two key aspects. First, in their model firms simultaneously decide on advertising and prices, while in my framework firms choose simultaneously their R&D levels at a first stage and then, at a second stage, firms compete simultaneously in prices. This allows us to examine the strategic effects of R&D investment on price competition. Second, for the asymmetric case HM assume that firms have the same unit production cost and firms differ in their advertising costs; both are exogenous. In my model, both firms face the same R&D cost, which is exogenous, and the unit production cost is endogenous (through the choices of R&D levels at the first stage). Therefore, the results of this chapter do not depend on exogenous R&D costs differences.

Finally, this chapter is related to Armstrong and Zhou (2011). They investigate three ways of becoming prominent in search markets: i) affecting an intermediary's sales efforts through commission payments; ii) advertising prices on a price comparison website; iii) consumers might first consider their existing supplier when they purchase a new product. In this chapter I assume prominence is exogenous. However, if there is a procedure to endogenised prominence in this framework we would expect that a prominent firm has the incentive to make aggressive investment in cost reduction in order to get a prominent position in the market.

2.2 The Model

I model the idea that firms invest in R&D to reduce their unit production costs, which affect price competition in a market where consumers search sequentially. When firms are ex ante equivalent consumers search for a product randomly among firms. But, when a firm has a prominent position, all consumers start searching for a product visiting first the prominent firm. As in AVZ, the prominent position is exogenously given.

2.2.1 Firms

There are two firms in the market ($i = 1, 2$), each of which sells a single differentiated product. Firm i invests $\gamma_i \in (0, \infty]$ in R&D to reduce its unit production cost $c_i(\gamma_i) = \gamma_i^{-1}$. Note that each firm benefits only from its own investment in cost reduction, therefore there are no spillover effects. The cost of R&D is quadratic, that is for a direct reduction in unit production cost of γ_i firm i must pay $R_i(\gamma_i) = k\gamma_i^2$, with $k > 0$. Firms maximise their profits, choosing R&D investments γ_i and prices p_i. In AVZ firms only choose their prices and, hence, any possible asymmetry is exogenous. In my framework, by allowing firms to choose their cost-reduction investments, the efficiency asymmetry is endogenous.

2.2.2 Consumers

There is a unit mass of consumers. Each consumer wishes to purchase one unit of the product from the market. I assume the values attached by each consumer to the different brands, u_i, are realizations of independent and identically distributed random variables with distribution function $G(u)$, over a finite support $[\underline{u}, \overline{u}] \in \mathbb{R}_+$, and strictly positive, continuously differentiable, and logconcave density function $g(u)$.[7] Match values are realised independently across consumers. Consumers' surplus from buying firm i's product is $u_i - p_i$. Consumers seek to maximise their surplus.

Before visiting a firm, consumers are uninformed about prices and match values. To discover a firm's price and product's value (i.e, how much the product would fit the consumer's taste) a consumer incurs a search cost $s > 0$. I adopt the standard assumptions that consumers have rational expectations[8] and beliefs are passive (i.e, a consumer does not change her belief about the price of the unsampled firm if she observes one firm charging an unexpected price). I assume searching is without replacement and with costless recall (consumers can go back to a visited store without additional cost and buy at the price discovered at the first visited firm).

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[7]This ensures that the hazard rate is increasing and holds for many common distributions, like the uniform distribution used later. For more details see Bagnoli and Bergstrom (2005).

[8]With rational expectations $p_i^e = p_i$, where p_i^e is the consumer's expected price from firm i.

Assumption 1 (A1): $\underline{u}$ is sufficiently high such that the market is fully covered.

A1 implies that every consumer in the market buys a product.

Consumers decide to buy a product according to the following sequential search process. A consumer will start visiting firm i if her surplus is $v_i - p_i - s > 0$, where v_i is the expected valuation of firm i's product. When visiting firm i, the consumer has to decide if she buys from i or should continue searching on firm j, so she compares the observed surplus of buying from firm i, $u_i - p_i$,[9] with the expected surplus of visiting firm j. If the consumer visits firm j, she has to decide if she buys from j or goes back to firm i, so she compares the observed surplus of buying from j, $u_j - p_j$, with the observed surplus of going back to firm i, $u_i - p_i$.[10]

2.2.3 Timing

The precise timing is as follows. At *stage 1*, firms simultaneously choose their R&D levels γ_i. Then, at *stage 2* and after observing actions chosen at stage one, firms simultaneously choose their prices p_i considering consumers' search behaviour. Finally, at *stage 3*, consumers search optimally to maximise their surplus $u_i - p_i$.

2.3 Analysis

In this Subsection I solve the three-stage game using backward induction. In Subsection 2.3.1 I solve the benchmark case (random search), and in Subsection 2.3.2 I solve the prominence case. Afterwards, I compare the random search equilibrium with the prominence equilibrium. Finally, I study some comparative statics of the prominence equilibria in terms of search costs.

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[9] Notice that s is a sunk cost.

[10] The consumer knows u_i when she visits firm j because firm i has been visited first.

2.3.1 Random Search

Consumer Search

The optimal consumer search (stage three) is derived from the sequential search process described in Subsection 2.2.2, and it is stated in the following Lemma.

Lemma 5 (Stopping rule). *The optimal search rule when a consumer has decided to visit firm i ($v_i > p_i + s$) is*

- *If $u_i > u_i^*$, buy immediately from i (stop searching), otherwise visit firm j,*

- *If $u_i < u_i^*$, search on firm j and buy from it if $u_j - p_j > u_i - p_i$, otherwise go back to firm i.*

The cut-off utility u_i^* solves

$$u_i^* - p_i = (u_i^* - p_i) \int_{\underline{u}}^{u_i^* - p_i + p_j} g(u_j) du_j + \int_{u_i^* - p_i + p_j}^{\overline{u}} (u_j - p_j) g(u_j) du_j - s \quad (2.1)$$

The *cut-off utility* u_i^* is the utility level such that the consumer is indifferent between buying from firm i or continue searching on firm j. Notice that *a priori* the cut-off utility might be inside or outside the support of $G(u)$. This depends on the price relationship between both firms. I restrict the analysis to the case in which u_i^* lies inside the support of $G(u)$, that is $u_i^* \in [\underline{u}, \overline{u}]$.[11]

Equilibrium prices with random search

Consumers search optimally according to the stopping rule in Lemma 1. Given this search behaviour, at stage two firms set simultaneously their prices to maximise their profits. Now, I derive the demand function for firm i assuming half of the consumers start visiting firm i. Suppose firm i charges a price p_i while the other firm offers a price p_j, then consumers who buy from firm i are:

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[11]If $u_i^* = \underline{u}$ those consumers who start visiting firm i are going to stop at that firm, that is they are not going to search on firm j. When $u_i^* = u_j^* = \underline{u}$ no consumer want to search beyond the first visited firm. On the other extreme case, when $u_i^* = \overline{u}$ those consumers who start visiting firm i are not going to stop at that firm, that is they are going to search on firm j. If $u_i^* = u_j^* = \overline{u}$ all consumers are going to search all firms in the market before buying a product. In this case, there is no incentive for a firm to be the prominent.

- Consumers who start visiting firm i and buy from it immediately (without visiting firm j) because $u_i > u_i^*$. The mass of these consumers is $\frac{1}{2}\left[1 - G(u_i^*)\right]$. (Group A)

- Consumers who visited firm i but the product did not fit well on their taste ($u_i < u_i^*$), they visited firm j and discovered that $u_j - p_j < u_i - p_i$, so they decided to go back to firm i. The mass of these consumers is
$\frac{1}{2}\int_{\underline{u}}^{u_i^*} g(u_i) \int_{\underline{u}}^{u_i - p_i + p_j} g(u_j)du_j\, du_i$. (Group B)

- Consumers who start visiting firm j but the product did not fit well on their taste ($u_j < u_j^*$), they visited firm i and discovered that $u_i - p_i > u_j - p_j$, so they buy from firm i. The mass of these consumers is $\frac{1}{2}\int_{\underline{u}}^{u_j^*} g(u_j) \int_{u_j - p_j + p_i}^{\overline{u}} g(u_i)du_i\, du_j$. (Group C)

Therefore, firm i's demand function is

$$
q_i(p_i, p_j) = \frac{1}{2}\left[(1 - G(u_i^*)) + \int_{\underline{u}}^{u_j^*} g(u)\left[1 - G(u - p_j + p_i)\right] du + \int_{\underline{u}}^{u_i^*} g(u)\, G(u - p_i + p_j)du \right]
$$

(2.2)

The first two terms in the RHS of (2.2) is the *fresh demand*, that is those consumers who buy immediately from firm i when consumers visit i. The last term of (2.2) is the *returning demand*, that is those consumers who visited firm j but they could not find a good deal so they decided to go back and buy from i.[12]

Given the demand function (2.2), firm i's profit is

$$
\Pi_i = \left(p_i - \gamma_i^{-1}\right) q_i(p_i, p_j) - k\gamma_i^2
$$

(2.3)

In order to find analytical expressions assume that u_i are random variables in a uniform distribution function $G(u)$ with support $[\underline{u}, \overline{u}]$. In this case, the *cut-off*

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[12]Notice that when $u_i^* = u_j^* = \underline{u}$ there is no search beyond the first visited firm and the demand function is $q_i = \frac{1}{2}\left[1 - G(\underline{u})\right] = \frac{1}{2}$. Therefore, in this case the market is split between both firms and each firm serves half of the market and behaves as a local monopoly. On the other hand, when $u_i^* = u_j^* = \overline{u}$ the demand function is $q_i = \frac{1}{2}\left[\int_{\underline{u}}^{\overline{u}} g(u)\left[1 - G(u - p_j + p_i)\right] du + \int_{\underline{u}}^{\overline{u}} g(u)G(u - p_i + p_j)du\right]$.

utility is $u_i^* = \bar{u} + p_i - p_j - \sqrt{2s}\sqrt{(\bar{u} - \underline{u})}$,[13] and firm i's demand function is

$$q_i(p_i, p_j) = \frac{1}{2} - \frac{p_i - p_j}{\bar{u} - \underline{u}} \qquad (2.4)$$

Notice that the demand function (2.4) does not depend directly on the search costs. The reason is as follows. With a higher search cost, both u_i^* and u_j^* are reduced. Hence, we have the following effects:

- some consumers who start visiting firm i become less choosy and will not search on firm j. This is a positive effect on firm i's demand and a negative effect on firm j's demand, due to Group A;

- some consumers are more reluctant to go back to firm i. This is a negative effect on firm i's demand and a positive effect on firm j's demand, due to Group B;

- the number of consumers who buy from firm i after visiting firm j is reduced. This is a negative effect on firm i's demand and a positive effect on firm j's demand, due to Group C.

Given the assumption of two firms in the market, all these effects cancelled out in the case of a uniform distribution.

Replacing the demand function (2.4) in the profit function (2.3), the FOCs are:

$$\frac{1}{2} + \frac{p_j - 2p_i}{\bar{u} - \underline{u}} + \frac{1}{(\bar{u} - \underline{u})\gamma_i} = 0 \qquad (2.5)$$

$$\frac{1}{2} + \frac{p_i - 2p_j}{\bar{u} - \underline{u}} + \frac{1}{(\bar{u} - \underline{u})\gamma_j} = 0 \qquad (2.6)$$

---

[13]There is a second root for the cut off utility: $u_i^* = \bar{u} + p_i - p_j + \sqrt{2s}\sqrt{(\bar{u} - \underline{u})}$. However, for $\bar{u} - \underline{u} = 1$ (used later) the demand functions are the same as (2.4), hence the equilibrium is the same.

Rearranging firm i's first order condition,[14] firm i's best response function is:

$$p_i(p_j) \;=\; \frac{\overline{u} - \underline{u}}{4} + \frac{1}{2\gamma_i} + \frac{p_j}{2} \tag{2.7}$$

The slope of the best reply function is positive: $\frac{\partial p_i(p_j)}{\partial p_j} = \frac{1}{2} > 0$. This implies that prices decision at stage two are strategic substitutes.

By solving the first order conditions (2.5) and (2.6), the equilibrium prices with random search are:

$$p_i^*(\gamma_i, \gamma_j) \;=\; \frac{\overline{u} - \underline{u}}{2} + \frac{2}{3\gamma_i} + \frac{1}{3\gamma_j} \tag{2.8}$$

Lemma 6. *Assume a uniform distribution and half of the consumers start searching firm i. The firm which invest more (less) in R&D charges a lower (higher) price than its rival.*

The interpretation of Lemma 6 is straightforward. For a given amount of firm i's investment, firm i's price response in term of the rival investment is $\frac{\partial p_i^*(\gamma_i, \gamma_j)}{\partial \gamma_j} = -\frac{1}{3\gamma_j^2} < 0$. Intuitively, when firm j invests more in cost-reduction it charges a lower price, $\frac{\partial p_j^*(\gamma_j, \gamma_i)}{\partial \gamma_j} < 0$. Therefore, it is not profitable for firm i to keep its price, hence firm i will also reduce its price. This means technological innovation in cost-reduction are strategic substitutes, in the terminology of Bulow et al. (1985).

Equilibrium R&D with random search

At stage one firms choose their optimal level of R&D. Firm i's payoff is $\Pi_i(\gamma_i, \gamma_j)$, where $\Pi_i(\gamma_i, \gamma_j)$ results from replacing the equilibrium prices (2.8) into the profit function (2.3). This yields a reduced-form expression for firm i's payoff in terms of production cost reductions and the cost of R&D. Thus, the equilibrium R&D level is given by $\gamma_i^* \in \arg\max_{\gamma_i} \Pi_i(\gamma_i, \gamma_j^*)$.

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[14]The second order condition in this case is the same for both firms: $-\frac{2}{\overline{u} - \underline{u}} < 0$.

The equilibrium level γ_i^* must satisfy the first order condition:[15]

$$\frac{1}{6\gamma_i} + \frac{1}{9(\overline{u} - \underline{u})\gamma_i\gamma_j} - \frac{1}{9(\overline{u} - \underline{u})\gamma_i^2} - 2k\gamma_i = 0 \qquad (2.9)$$

Consequently, we have the following result.

Proposition 2. *When $G(u)$ has a uniform distribution with $\overline{u} - \underline{u} = 1$ and consumers search randomly, the industry equilibrium is as follows:*

- $\gamma_i^* = \gamma_j^* = \gamma^* = \frac{1}{(6k)^{\frac{1}{3}}}$;

- $p_i^* \left(\gamma_i^*, \gamma_j^*\right) = p_j^* \left(\gamma_j^*, \gamma_i^*\right) = p^* = \frac{1}{2} + (6k)^{\frac{1}{3}}$;

- $\Pi_i^* \left(\gamma_i^*, \gamma_j^*\right) = \Pi_j^* \left(\gamma_j^*, \gamma_i^*\right) = \Pi^* = \frac{1}{4} - \left(\frac{k}{6}\right)^{\frac{1}{3}}$;

for $k \in (0, \frac{3}{32}]$.

Proposition 2 shows that with random search the industry equilibrium is symmetric. When consumers search for a product randomly among the suppliers in the market, firms face a symmetric demand function and prices are symmetric in equilibrium. Therefore, firms choose their R&D levels in a symmetric way. In this case, firms have no incentive to invest more or less than the rival because they maximise their profits serving half of the market, $q_i^* = q_j^* = q^* = \frac{1}{2}$.

Finally, with random search and uniform distribution with a support $[4, 5]$, A1 is satisfied and the equilibrium *cut-off utility* is $u_i^* = 5 - \sqrt{2s}$. Additionally, if $s \in [0, \frac{1}{2}]$ then $u_i^* \in [4, 5]$.

2.3.2 Prominence

Equilibrium prices with prominence

In order to analyse the prominence case let assume, following AVZ, that the prominent firm is sampled first by all consumers. Without loss of generality, suppose firm

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[15]The equilibrium R&D level must also satisfy the second order condition: $-3 \left(\overline{u} - \underline{u}\right) \left(1 + 3k\gamma_i^3\right) \gamma_i\gamma_j - 2\gamma_i + 3\gamma_j < 0$. This implies that for maximizing profits γ_i cannot be too closed to zero (if $\gamma_i \to 0$ then the second order condition is for a minimum).

i is the prominent firm and firm j is the non-prominent firm. Consumers are going to follow an equivalent stopping rule as in Lemma 1. As a consequence, the only relevant *cut-off utility* is u_i^* because in this case all consumers start visiting firm i. Given consumers' search behaviour, at stage two firms are going to set their prices to maximise their profits. In order to derive the demand functions, suppose firm i charges a price p_i while the other firm offers a price p_j, then consumers who buy from firm i are:

- Consumers who buy from i immediately (without visiting firm j) because $u_i > u_i^*$. The mass of these consumers is $[1 - G(u_i^*)]$.

- Consumers who visited firm i but the product did not fit well on their taste $(u_i < u_i^*)$, they visited firm j and discovered that $u_j - p_j < u_i - p_i$, so they decided to go back to firm i. The mass of these consumers is $\int_{\underline{u}}^{u_i^*} g(u_i) \int_{\underline{u}}^{u_i - p_i + p_j} g(u_j) du_j \, du_i$.

On the other hand, the consumers who buy from firm j are:

- Consumers who visited firm i but the product did not fit well on their taste $(u_i < u_i^*)$, they visited firm j and discovered that $u_j - p_j > u_i - p_i$, so they buy from firm j. The mass of these consumers is $\int_{\underline{u}}^{u_i^*} g(u_i) \int_{u_j - p_j + p_i}^{\overline{u}} g(u_j) du_j \, du_i$.

Therefore, demand functions for the prominent and non-prominent firms are

$$q_i\left(p_i, p_j\right) = \left(1 - G(u_i^*)\right) + \int_{\underline{u}}^{u_i^*} g(u)\, G\left(u - p_i + p_j\right) du \qquad (2.10)$$

$$q_j\left(p_j, p_i\right) = \int_{\underline{u}}^{u_i^*} g(u)\left[1 - G\left(u - p_i + p_j\right)\right] du \qquad (2.11)$$

The first term in the RHS of (2.10) is the *fresh demand*, that is those consumers who buy immediately from the prominent firm without visiting the non-prominent

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firm. The last term of (2.10) is the *returning demand,* that is those consumers who visited the non-prominent firm but they could not find a good deal so they decided to go back and buy from the prominent firm. Since there are two firms in the market, the non-prominent firm has only *fresh demand.*[16]

In order to find analytical expressions assume u_i are random variables in a uniform distribution function $G(u)$ with support $[\underline{u}, \overline{u}]$, as I have done in the random search case. Thus, the demand functions are

$$q_i(p_i, p_j) = \frac{1}{2} + \frac{s}{\overline{u} - \underline{u}} - \frac{(p_i - p_j)^2}{2(\overline{u} - \underline{u})^2} - \frac{p_i - p_j}{\overline{u} - \underline{u}} \tag{2.12}$$

$$q_j(p_j, p_i) = \frac{1}{2} - \frac{s}{\overline{u} - \underline{u}} + \frac{(p_i - p_j)^2}{2(\overline{u} - \underline{u})^2} + \frac{p_i - p_j}{\overline{u} - \underline{u}} \tag{2.13}$$

Notice the difference between the demand functions with prominence, (2.12) and (2.13), and the demand function with random search, (2.4). With random search $\frac{\partial q_i}{\partial s} = \frac{\partial q_j}{\partial s} = 0$. However, with prominence $\frac{\partial q_i}{\partial s} > 0$ and $\frac{\partial q_j}{\partial s} < 0$, that is a higher search cost is an advantage for the prominent firm while it is a disadvantage for the non-prominent firm. In the prominence case, if $p_i = p_j$ then $q_i(p_i, p_j) > q_j(p_j, p_i)$ due to the assumption $s > 0$.[17] Therefore, prominence introduces the first possible source of asymmetry in this model.

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[16]If $u_i^* = \underline{u}$ there is no search beyond the prominent firm. This implies that the demand function for the prominent firm is $q_i = [1 - G(\underline{u})] = 1$ and the non-prominent has no demand, $q_j = 0$. Therefore, the market is a monopoly with all consumers buying from the prominent firm. When $u_i^* = \overline{u}$ all consumers are going to search on the non-prominent firm, so prominent's demand function is $q_i = \int_{\underline{u}}^{\overline{u}} g(u) G(u - p_i + p_j) \, du$, and the demand for the non-prominent firm is $q_j = \int_{\underline{u}}^{\overline{u}} g(u) [1 - G(u - p_i + p_j)] \, du$. Given A1, $q_i + q_j = 1$, then $q_i = G(u - p_i + p_j)$ and $q_j = 1 - G(u - p_i + p_j)$. Therefore, in this case there is no advantage of being prominent.

[17]For the same prices being prominent implies that the firm has an advantage because is able to attract more demand.

With a uniform distribution and all consumers start visiting the prominent firm first, equilibrium prices satisfy the following first order conditions:

$$\frac{1}{2} + \frac{s}{\overline{u} - \underline{u}} - \frac{(p_i - p_j)^2}{2(\overline{u} - \underline{u})^2} - \frac{p_i - p_j}{\overline{u} - \underline{u}} + (p_i - \gamma_i^{-1})\left(-\frac{p_i - p_j}{(\overline{u} - \underline{u})^2} - \frac{1}{\overline{u} - \underline{u}}\right) = 0 \quad (2.14)$$

$$\frac{1}{2} - \frac{s}{\overline{u} - \underline{u}} + \frac{(p_i - p_j)^2}{2(\overline{u} - \underline{u})^2} + \frac{p_i - p_j}{\overline{u} - \underline{u}} + (p_j - \gamma_j^{-1})\left(-\frac{p_i - p_j}{(\overline{u} - \underline{u})^2} - \frac{1}{\overline{u} - \underline{u}}\right) = 0 \quad (2.15)$$

It is clear that the asymmetry caused by prominence complicates the analysis substantially. The non-linearity of the first order conditions[18] implies that it is very difficult to show analytically tractable equations. In order to solve analytically the equilibrium prices I assume a support $[\underline{u}, \overline{u}] = [4, 5]$.[19] Solving the system of FOCs, the equilibrium prices are:

$$p_i^*(\gamma_i, \gamma_j) = \frac{1}{\gamma_i} + \frac{11 + 8s + (2 - m)m - (1 + m)A}{4(1 + m + A)}$$

$$p_j^*(\gamma_j, \gamma_i) = \frac{1}{\gamma_j} + \frac{5 - 8s - (2 - m)m + (1 + m)A}{4(1 + m + A)} \quad (2.16)$$

where $m = \frac{1}{\gamma_i} - \frac{1}{\gamma_j}$ and $A = \sqrt{9 - 6m + m^2 + 16s}$.[20]

Since it is difficult to see analytically $p_i^*(\gamma_i, \gamma_j)$ best response in terms of γ_j and $p_j^*(\gamma_j, \gamma_i)$ best response in terms of γ_i, in Appendix 4.5 I plot firm i's equilibrium price in terms of the R&D effort of the rival, γ_j, fixing γ_i. Both equilibrium prices have the expected path, that is a firm charges a lower price when the rival invests

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[18]The second order conditions for the prominent firm and non-prominent firm are $-\frac{2}{\overline{u} - \underline{u}} + \frac{2(p_j - p_i)}{(\overline{u} - \underline{u})^2} - \frac{p_i - \gamma_i^{-1}}{(\overline{u} - \underline{u})^2} < 0$, and $-\frac{2}{\overline{u} - \underline{u}} + \frac{2(p_j - p_i)}{(\overline{u} - \underline{u})^2} + \frac{p_j - \gamma_j^{-1}}{(\overline{u} - \underline{u})^2} < 0$, respectively.

[19]Notice from the demand functions, (2.12) and (2.13), and from the FOCs, (2.14) and (2.15), that the difference between the upper and lower bound of the uniform distribution is relevant. I assume $\overline{u} - \underline{u} = 1$ as in AVZ and HM, which allows to simplify the solution of the model. Additionally, given the demand functions and FOCs, it is possible to choose $\underline{u}$ sufficiently high such that A1 holds in equilibrium.

[20]There is a second root for prices, however this implies that the profit function is not concave.

more in R&D. The difference is that the best response function of the prominent firm is more convex than the best response function of the non-prominent firm. This implies that the prominent firm price response (in terms of the non-prominent investment) is more aggressive than the non-prominent price response (in terms of the prominent firm investment). Intuitively, when the prominent firm invests more than its rival, it is able to charge a lower price because is more efficient than the non-prominent firm. On the other hand, the prominent firm may charge a higher price because of its advantage position in the consumers' search process: by charging a slightly higher price than the non-prominent firm, the prominent firm can have a higher demand because some consumers still want to buy from the prominent firm. This is the second possible asymmetry in this framework with prominence and R&D investment decisions.

Equilibrium R&D with prominence

At stage one firms choose their optimal level of R&D. Firm i's payoff is $\Pi_i(\gamma_i, \gamma_j)$, where $\Pi_i(\gamma_i, \gamma_j)$ results from replacing the equilibrium prices (2.16) into the profit function. The equilibrium R&D level is given by $\gamma_i^* \in \arg\max_{\gamma_i} \Pi_i(\gamma_i, \gamma_j^*)$.

Since it is not possible to find analytical expressions, I use numerical analysis to find the R&D equilibrium in the prominence case. I solve for γ_i and γ_j for different values of k, considering $s = 0.05$ and the uniform distribution with support $[4, 5]$. Comparing the prominence equilibrium with the random search equilibrium, we have the following result. (Table 2.1 shows the numerical analysis comparison.)

Proposition 3. *If $G(u)$ has a uniform distribution with $\overline{u} - \underline{u} = 1$ and s is not high:*

(a) $\gamma_i^* > \gamma_j^* > \gamma^*$ for low k, and

    $\gamma_i^* > \gamma^* > \gamma_j^*$ for high k;

(b) $p_i^* < p_j^* < p^*$ for sufficiently low k,

    $p_i^* < p^* < p_j^*$ for not too low k, and

    $p^* < p_i^* < p_j^*$ for high k;

(c) $q_i^* > q^* > q_j^*$;

(d) $\Pi_i^* > \Pi^* > \Pi_j^*$.

The comparison between the equilibrium with random search (p^*, γ^*) and the equilibrium with prominence $(p_i^*, p_j^*, \gamma_i^*, \gamma_j^*)$ gives results consistent with the previous literature and also novel results.

The main results in Proposition 3 are the following. First, the prominent firm is the most efficient firm (chooses the highest R&D level). The effect of prominence on the prominent firm is clear; this firm has the incentive to invest more in R&D irrespective of the R&D cost. However, the effect of prominence on the non-prominent firm depends on the R&D cost. If the R&D cost is high, the non-prominent firm is the least efficient firm (chooses the lowest R&D level). In this case, R&D is costly and the efficiency difference between the prominent and non-prominent firms is large. Hence, the non-prominent firm has the incentive to invest less than when consumers search randomly. On the other hand, if the R&D cost is low the non-prominent firm investment is lower than in the random search case. In this case, R&D is costless and the efficiency difference between the prominent and non-prominent firms is small, hence the non-prominent firm investment is higher than the investment when consumers search randomly.

Second, the effect of prominence on prices depends on the firms' efficiency asymmetry. If the efficiency asymmetry is very small, prices with prominence are lower than prices with random search. In this case, the prominent firm charges the lowest price, and the non-prominent firm charges a lower price than with random search. This implies that both the prominent and non-prominent firms invest more in R&D than with random search and price competition is tough. If the efficiency asymmetry is large, prices with prominence are higher than prices with random search. In this case, the non-prominent firm has less incentive to invest in R&D, has a high marginal cost and charges a high price. The prominent firm has the incentive to charge a higher price than with random search due to strategic effect: the prominent firm is able to charge a higher price because the non-prominent rival charges a higher

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price. In other words, when the efficiency asymmetry is high price competition is softened. Finally, the intermediate case arise when the efficiency asymmetry is not too low; the prominent firm charges the lowest price and the non-prominent firm charges the highest price compare to the price with random search.

It is noteworthy that prominence with endogenous firms' efficiency allows to find new results from those findings in the literature considering prominence with exogenous firms' efficiency. HM show that the more advertising-efficient firm charges the lowest price, the less advertising-efficient firm charges the highest price, and the price with symmetric advertising technologies lies between those prices (Remark 1). AVZ find the same relationship between prices when firms have no quality differences (symmetric case). Both HM and AVZ results correspond to the intermediate case in this framework: $p_i^* < p^* < p_j^*$. However, when firms' efficiency is endogenous I find a broader relationship in terms of prices than with exogenous firms' efficiency case (HM and AVZ studies). This result is due to the fact that R&D investment choices are in a previous stage than firms' price choices. Therefore, my model captures the relationship between R&D investment (cost-reduction innovation stage) and the strategic effects on market prices (price competition stage).

In this chapter, since firms choose their cost-reduction investment levels and then compete in prices, there are two different effects. The first one is that the prominent firm is able to charge a lower price because is the most efficient firm: the prominent firm invests more in R&D and has a lower marginal cost than the non-prominent rival and the random search case (lower price due to cost-efficiency). On the other hand, the prominent firm is able to charge a higher price because the non-prominent rival charges a higher price: when a firm is prominent, its non-prominent rival invest less in R&D, has a higher marginal cost and, thus, charges a higher price. Hence, the prominent firm faces less price competition pressure and is able to charge a higher price (higher price due to strategic effect). Which effect dominates depends on the firms' efficiency asymmetry. If R&D is costless, the efficiency asymmetry is small and the cost-efficiency effect dominates the strategic effect. Hence, prices

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Table 2.1: Random search vs Prominence equilibrium[a]

k	R&D			Prices			Profits		
	γ^*	γ_i^*	γ_j^*	p^*	p_i^*	p_j^*	Π^*	Π_i^*	Π_j^*
0.00075	6.057	6.990	6.811	0.665	0.615	0.644	0.222	0.224	0.189
0.001	5.503	6.350	6.188	0.682	0.629	0.658	0.220	0.220	0.186
0.005	3.218	3.539	2.851	0.811	0.806	0.817	0.198	0.226	0.169
0.010	2.554	2.823	2.247	0.891	0.897	0.900	0.185	0.219	0.154
0.025	1.882	2.099	1.633	1.031	1.045	1.056	0.161	0.209	0.128
0.050	1.494	1.684	1.274	1.169	1.190	1.219	0.138	0.203	0.102
0.075	1.305	1.484	1.096	1.266	1.294	1.338	0.122	0.203	0.083

[a] Calculations for the prominence case have been done assuming $s = 0.05$.

are lower with prominence than with random search. If the R&D cost is high, efficiency asymmetry is large and the strategic effect dominates the cost-efficiency effect. Hence, prices with prominence are higher than prices with random search. If R&D cost is not too low we have the intermediate case.

Welfare analysis

The next step of the analysis is the implication of prominence on welfare. For this, I compare the social welfare under random search versus the social welfare with prominence. I consider the standard welfare definition, that is consumer surplus plus industry profits (net of the R&D costs). Consumer surplus calculations are explained in Appendix 4.6.

Proposition 4. *When a firm is prominent, consumer surplus and social welfare are higher than with random search.*

This result is different from the main welfare result in AVZ. They show that when firms are homogeneous in terms of quality (symmetric case), consumer surplus and social welfare with prominence are lower than with random search (Proposition 3 and 5).[21]

On the other hand, AVZ show that when there are heterogeneous product qualities (asymmetric case) consumer surplus and social welfare are higher with promi-

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[21]They used a similar argument as in Varian (1985) for the welfare effects of price discrimination.

Table 2.2: Social Welfare Comparison[b]

k	Consumer Surplus		Industry Profits		Social Welfare	
	Random	Prominence	Random	Prominence	Random	Prominence
0.00075	3.859	4.039	0.445	0.413	4.304	4.453
0.001	3.842	4.022	0.439	0.406	4.282	4.429
0.005	3.713	3.763	0.396	0.395	4.110	4.157
0.010	3.632	3.640	0.370	0.373	4.002	4.013
0.025	3.493	3.527	0.323	0.337	3.815	3.863
0.050	3.354	3.443	0.277	0.305	3.631	3.748
0.075	3.258	3.383	0.245	0.286	3.502	3.669

[b] Calculations have been done assuming $s = 0.05$.

nence (Proposition 6). I find also that prominence increases consumer surplus. However, this result has a different explanation from AVZ. In their paper prominence is a signal of high quality (and high price), so prominence guides consumers toward better and better value products. Hence, the prominent firm offers the highest quality and charges the highest price. In my framework, the prominent firm always charges less than the non-prominent firm. Consumer surplus from those consumers who buy immediately from the prominent firm is higher than the consumer surplus from those consumers who buy immediately with random search. For other consumers (consumers who buy from the rival firm or go back to the first visited firm), the consumer surplus with prominence is lower in most cases than with random search (Appendix 4.6). As a consequence, the gain in consumer surplus from those who buy immediately offsets the loss in consumer surplus from the other consumers. This suggests that the number of search and total search costs in equilibrium with prominence are lower than with random search.

Finally, in AVZ prominence increases industry profits. In my framework, when a firm is prominent industry profits are lower than with random search if the R&D cost is low. On the contrary, industry profits are higher with prominence than with random search if the R&D cost is high.

Comparative statics

Now I analyse the comparative statics for the prominence equilibrium in terms of search costs. For this I have to resort to a numerical analysis; I solve γ_i and γ_j for different values of s assuming $k = 0.05$.[22] Table 2.3 shows the numerical simulations for Proposition 5.

Proposition 5. *The comparative statics of the SPE in the prominence case are:*

(a) *when search costs increase, the prominent firm invests more in R&D while the non-prominent firm invests less;*

(b) *prices are non-monotonic in search costs.*

The result in proposition 5 *(a)* can be explained in terms of two opposite effects: market share and business stealing. The first one means that, for a given search cost, a firm has the incentive to invest more in R&D if its market share is higher because, by doing so, increases its unit profits. The second effect means that, for a given search cost, a firm has the incentive to invest in cost-reduction because is able to steal a rival's business. In the case of the prominent firm, the market share effect is positive: given the higher market share for this firm in equilibrium, a higher search cost increases its market share. This implies that the prominent firm has the incentive to invest more in R&D. On the other hand, the business stealing effect is negative: given the higher demand for the prominent firm, when search costs are higher, the business stealing effect is weaker. In the case of the non-prominent firm, the market share effect is negative: since the market share for the non-prominent firm is lower in equilibrium, an increase in search cost reduces the non-prominent firm's incentive to invest in R&D. On the other hand, the business stealing effect is positive: as searching becomes more costly consumers tend to be less choosy with the prominent firm, hence the non-prominent firm has the incentive to invest more to attract consumers and compensate the disadvantage of been visited later. In this framework, the market share effect dominates the business stealing effect.

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[22]I have done numerical analysis for different values of the parameter k and the results are qualitatively equivalent.

Proposition 5 *(b)* shows that price behaviour in terms of search costs is different from AVZ and HM. For the symmetric case in AVZ, prices are monotonically decreasing with lower search costs and both prices converge as searching becomes costless (Figure 2). For the symmetric case in HM, an increase in search costs raises the equilibrium prices of both the prominent and non-prominent firms (Proposition 2). My results, on the other hand, show that prices are non-monotonic with search costs. Indeed, as s moves away from zero, prices for the prominent firm increase and then decrease, while prices for the non-prominent firm decrease and then increase. On top of this, contrary to AVZ, when searching becomes costless the non-prominent firm charges a higher price than the prominent firm.

The result that prices are increasing in the search costs is standard in the literature (see, e.g., Anderson and Renault (1999), who show that equilibrium price is an increasing function of the search costs in a single-product search model). The usual intuition is that higher search costs deter consumers from looking around for a better deal, which gives firms more market power. But this result might not be necessarily the same in a framework where prominence is exogenous and R&D investment is endogenous because there are different effects that may counterbalance, and eventually offset, the initial effect of a higher search cost. Indeed, prices follow a different path with search costs because prices are affected by the R&D choices. In the case of the prominent firm, when s moves away from zero, the firm has the incentive to charge more because of the positive effect of search costs on its demand function. But when search costs are sufficiently high, the prominent firm is able to reduce its price caused by the cost advantage due to higher R&D investment. This allows the prominent firm to attract more demand, in particular to increase the number of consumers who want to go back to buy from it after visiting the non-prominent rival. In the case of the non-prominent firm, when s moves away from zero, the firm reduces its price in order to keep those consumers who visit the non-prominent firm and, by doing so, avoid consumers going back to the prominent firm. But when search costs are sufficiently high, the non-prominent firm charges

Table 2.3: Equilibrium with Prominence[c]

s	R&D		Prices		Profits		Demand	
	γ_i^*	γ_j^*	p_i^*	p_j^*	Π_i^*	Π_j^*	q_i^*	q_j^*
0.010	1.6749	1.2833	1.1896	1.2423	0.1924	0.1208	0.5613	0.4387
0.025	1.6782	1.2800	1.1896	1.2333	0.1962	0.1135	0.5677	0.4323
0.050	1.6842	1.2736	1.1899	1.2191	0.2032	0.1017	0.5788	0.4212
0.075	1.6906	1.2660	1.1908	1.2061	0.2108	0.0904	0.5902	0.4098
0.100	1.6975	1.2574	1.1922	1.1941	0.2190	0.0797	0.6019	0.3981
0.125	1.7049	1.2477	1.1833	1.1941	0.2278	0.0695	0.6141	0.3859
0.150	1.7126	1.2369	1.1734	1.1965	0.2372	0.0597	0.6267	0.3733
0.200	1.7293	1.2119	1.1568	1.2027	0.2583	0.0416	0.6531	0.3469
0.300	1.7675	1.1454	1.1385	1.2227	0.3117	0.0108	0.7122	0.2878

[c] Calculations have been done assuming $k = 0.05$.

more because the non-prominent firm expects that those consumers who visit its store found a very bad offer in the prominent store. In this case, the usual intuition that firms get more market power when search costs are higher applies but only for a sufficiently high search costs.

Finally, the equilibrium prices are such that A1 holds in the numerical results. I also have done numerical simulations for a support $[\underline{u}, \overline{u}] = [4, 6]$ and the qualitative results are the same.

2.4   Conclusion

This chapter explores the effects of prominence on the industry equilibrium and social welfare. I considered a model of duopolistic competition with product differentiation where firms choose their R&D level to reduce their unit production cost and, then, set their prices in a market with sequential consumer search. In the benchmark case consumers start visiting a firm randomly, while in the prominence case all consumers visit the prominent firm first.

I find three main results when comparing prominence versus random search. First, the prominent firm is the most efficient firm irrespective of R&D cost. The non-prominent firm is the least efficient firm if R&D cost is high, and the non-prominent firm invest more in R&D than with random search if R&D cost is low.

Second, the effect of prominence on prices depends on firms' efficiency asymmetry. If the efficiency asymmetry is very small, prices with prominence are lower than prices with random search. If the efficiency asymmetry is large, prices with prominence are higher than prices with random search. The intermediate case is when the efficiency asymmetry is not too low; the prominent firm charges the lowest price and the non-prominent firm charges the highest price compare to the price with random search. Third, when a firm is prominent both consumer surplus and social welfare are higher than with random consumer search.

From the comparative static analysis with prominence the noteworthy results are the following. When searching becomes costly the prominent firm invests more in R&D and the non-prominent firm invests less in R&D. This result is explained in terms of market share and business stealing effects. For the prominent (non-prominent) firm, the market share effect is positive (negative) and the business stealing effect is negative (positive). In this model, the market share effect dominates the business stealing effect. Finally, prices are non-monotonic in search costs.

This chapter contributes to the economic analysis of R&D investment and to the implications of prominence. This framework allows to analyse the effects of endogenous R&D on price competition in a market where consumers search sequentially for a product. This chapter also contributes to the literature of prominence by allowing endogenous firms' efficiencies.

Chapter 3

Cash Incentives and Unhealthy Food Consumption

3.1 Introduction

Worldwide obesity has more than doubled since 1980 due to the increased intake of energy-dense foods with high levels of fat, salt and sugars with low fibre and vitamins; and a decrease in physical activity (World Health Organization (WHO)). In the US, 68% of the population over twenty years old was overweight or obese during 2007-2008.[1] In the UK, 57% of the population over sixteen years old was overweight or obese in 2008.

Overweight and obesity represent an economic problem for governments because they can cause negative externalities in terms of higher cost for the social security system. In the US, the obesity-attributable medical expenditures were 9.1% of total annual medical expenditures in 1998, and approximately *one-half* of these expenditures were financed by Medicare and Medicaid (Finkelstein et al. (2003)).[2] Most recently, Cawley and Meyerhoefer (2012) estimate that 20.6% of US national health expenditures are spent treating obesity-related illness. In the UK, the overweight

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[1]According to the WHO, a person is overweight when his Body Mass Index ($BMI = Kg/m^2$) is greater or equal to 25 and obese when his BMI is greater or equal to 30.

[2]Medicare is a social health insurance program for those aged 65 and over (or who meet other special criteria) and Medicaid is a social health insurance program for those eligible individuals with low incomes. Both of these programs are administered by the US government.

and obesity attributable medical expenditures were 16.2% of the total costs for the National Health Service (NHS) in 2006-07 (Scarborough et al. (2011)).

In order to reduce overweight and obesity, governments have responded with a variety of interventions, including traditional public policies like product taxes (e.g. tax on sugary beverages), and educational and informational programmes (e.g. promoting the advertisement of the health consequences associated with unhealthy food consumption and adding nutritional intake information to food packages). The US has announced new rules for school meals in order to reduce childhood obesity; subsiding healthy meals (e.g. fruits and vegetables).[3] Some European countries, like Denmark, Romania, Hungary and France, are promoting taxes on unhealthy foods.[4] Currently in the UK there is a discussion concerning the use of incentives to promote healthy behaviour.[5] This discussion has been motivated by some examples where local incentive schemes had been piloted, including people receiving cash for losing agreed amounts of weight, and children being rewarded with toys in exchange for eating more fruits and vegetables.

This chapter addresses the following questions: are taxes, subsidies and cash incentives effective in reducing unhealthy food consumption? If so, which one is the most appropriate policy to tackle the obesity problem?

In order to answer these questions, we use a model where consumers face an inter-temporal decision problem on the healthiness of the diet to follow. In this decision problem consumers have a trade-off between present and future consumption. Choosing an unhealthy diet has the advantage that it is less expensive and more convenient than the healthy alternative. However, whilst the healthy diet has no long term consequences in future utility, the unhealthy diet decreases future utility as it causes the agent to be less healthy. We also consider the existence of habit: the marginal utility from eating either healthy or unhealthy food at any point in time depends on the consumer's past diet. This means that, for instance, a consumer

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[3]The New York Times, January 25, 2012.
[4]See, for instance, BBC News October 01, 2011, www.bbc.co.uk/news/world-europe-15137948.
[5]NICE Citizens Council meeting, May 20-22, 2010, www.nice.org.uk.

who is used to follow a healthy diet derives more utility from eating healthy foods than a consumer who is used to eat unhealthy.

Within the setting just described, we consider the effects of three different policies on the level of unhealthy food consumption within the population: a *tax* on unhealthy food, a *subsidy* to healthy food and *cash incentives* in the form of a monetary reward to those consumers who decrease their unhealthy food intake. We use a calibration approach to simulate the effect of these three policies in two countries, the US and UK.

Our results suggest that cash incentives may be the most effective policy to tackle the obesity problem as it ensures a greater reduction in the number of people with unhealthy diets. Given the discount factor and the presence of habit, most consumers' behaviour depends on their initial diets. Hence, since most consumers initially choose unhealthy diets, motivating healthy food consumption via cash incentives has a significant positive effect on the aggregate level of unhealthy food consumption. However, when we compare the monetary benefits due to the reduction in costs for the social security system and the implementation costs of each policy, we find that cash incentives have very low net benefits. In fact, cash incentives may have negative long term benefits in the US and the UK. Thus, cash incentives as a desirable policy depends partly on the social, non-monetary, benefits of having a healthier population.

Tax is the least effective policy in reducing unhealthy food consumption. This is because of the differences in prices between healthy and unhealthy food; given the low cost of unhealthy food a tax has only a small effect on the relative price difference between the two types of food.

Subsidies, on the other hand, are relatively effective in reducing unhealthy food consumption and can lead to a significant surplus considering the savings to the social security system. Our calibration shows that with a 10% subsidy to healthy food the government can save in the long term up to $874 billion in the US and £56 billion in the UK.

The remaining of the chapter is organised as follows. Next we present a discussion on the relevant literature. In Subsection 3.2 we describe the model. A particular case of the model is presented in Subsection 3.3 whilst Subsection 3.4 provides the general case. In Subsection 3.5 we calibrate the model and simulate the effect of the different policies on the level of unhealthy food consumption in a population. Finally, Subsection 3.6 concludes.

3.1.1 Related literature

A large debate surrounds the eating habits and its health and economic consequences, yet not much work has been devoted to the issue of unhealthy food consumption. As Goel (2006) points out, the economics literature on obesity is still in its infancy. Only few papers have studied the agent's decision to consume unhealthy food while rationally considering the adverse effects on health. Levy (2002) considers a dynamic model of non-addictive eating to explain overweight, underweight and cyclical food consumption. He finds that when certain physiological, psychological, environmental and socio-cultural conditions are present an expected lifetime-utility maximiser chooses to be overweight. Yaniv (2002) uses a rational decision model to explain individual's deviation from a prescribed low-fat diet when there is the possibility that the consumer suffers a heart attack in the future. Yaniv finds that excess high-fat consumption may be due to the fact that the risk of a heart attack drives the individual to behave more oblivious of the future. Dragone and Savorelli (2012) study how social conformism can affect individual eating behaviour within a framework where individuals are aware of how food consumption affects body weight. They show that it can be optimal to be on a diet despite being underweight, or binge despite being overweight. The rest of the existing literature on this topic is empirical, and focuses mainly in the causes of the observed rise in overweight and obesity (see, for example, Cutler et al. (2003), Gruber and Frakes (2006), and Rashad et al. (2006)).

To our knowledge, only few papers analyse economic implications of different

government policies targeting consumers' diets. Some papers focus on the effect of educational information on food choices and body weight. Variyam and Cawley (2006) show that the Nutrition Labeling and the Education Act caused a decrease in body weight and the probability of begin obese among non-Hispanic white women in US. Acs and Lyles (2007) suggest that providing calorie information to individuals may only have small effects on food choices. Downs et al. (2009) goes further in this line by suggesting that providing calorie information may produce perverse effects such as promoting higher calorie consumption among dieters. Other papers focus on taxes and subsidies: Cash et al. (2004) argue that subsidies to fruits and vegetables (thin subsidies) encourages the consumption of healthier foods. Richards et al. (2007) suggest that price-based policies, sin taxes, or produce subsidies that change the expected future costs and benefits of consuming carbohydrate-intensive food can be effective in controlling excessive nutrient intake. Schroeter et al. (2008) argue that a small subsidy on diet soft drinks would be less weight-decreasing than a tax on caloric soft drinks. Yaniv et al. (2009) use a food-intake rational choice model to address the effect of a tax on junk food and a subsidy on healthy meals and show that a fat tax will reduce (increase) obesity for a non-weight-conscious (weight-conscious) individual, while a thin subsidy may increase obesity for a non-weight-conscious individual. Fletcher et al. (2010) show that soft drink taxation, as currently practised in the US, leads moderate reduction in soft drink consumption by children and adolescents. However, according to their study the reduction in soda consumption is completely offset by increases in consumption of other high-calorie drinks. Finally, Volpp et al. (2008) argue that financial incentives can be effective in inducing initial weight loss. The authors show in an experiment that a group of obese people lost weight after 16 weeks when given financial incentives. However, substantial amounts of weight were gained between the end of the weight loss phase and the follow-up three months later.

Our theoretical model builds on Becker and Murphy (1988) but focuses on the unhealthy food consumption problem instead of any general addictive behaviour.

Moreover, in our model time is discrete which allows us better calibration and interpretation of the model. In addition to this, we compare the effectiveness of three different policies to tackle the obesity problem. On top of that, in Becker and Murphy (1988) addicts respond more to permanent than to temporary changes in the prices of addictive goods whilst in our model a temporary policy that is able to change the consumer's habits can be as effective as a permanent one.

The main distinction between Schroeter et al. (2008), Yaniv et al. (2009) and this chapter is that they use a static rational choice model, while here we use a dynamic model. Furthermore, we allow for habit formation which is supported by the empirical evidence (e.g. Richards et al. (2007)).

3.2   The Model

Before dealing with a population of agents, we first deal with individual behaviour by considering the inter-temporal decision problem of a single consumer.

Time is discrete and denoted by $t = 0, 1, 2, \ldots$ Food can be of two types: healthy and unhealthy. We consider that unhealthy food is any food that would cause the consumer to become overweight given her life-style. Unhealthy food includes food that is high in fat, salt and sugar, and low in fibre and vitamins. We assume that the total amount of food the consumer purchases at any given period is normalised to one. The decision of the consumer at any given point in time is how much of unhealthy food $x \in [0, 1]$ to purchase. Denote by x^t the value of x at time t. Thus, $1 - x^t$ is the intake of healthy food in period t. We refer to a *diet* as the value of x. When comparing two diets, we say that a certain diet is *healthier* than another one if its amount of the unhealthy food x is lower. Note that instead of explicitly modeling the amount of food consumed and the life-style of the individual we summarise these two elements in the single variable x.

To model the long term effects of the different diets, we assume that although both the unhealthy and the healthy food are equally useful in feeding the consumer,

they differ in that the unhealthy food has a negative health effect in the future. The healthy food, on the other hand, has no long term consequences. Even though unhealthy food has a negative effect in the future, it may be attractive because it is more convenient than the alternative, healthy food: unhealthy food is cheaper in monetary terms (see, for instance, Monsivais (2010)), takes less time to cook (pre-cooked meals instead of meals cooked at home), is easier to find (fast food restaurant versus buying raw ingredients at the supermarket) and easier to dispose of (disposable packaging as opposed to doing the dishes). All these effects are summarised by assuming that healthy food is more expensive than unhealthy food.

Notice that whether a consumer gains weight (or loss) is determined by the Energy Balance Equation: weight gain is equal to the difference between energy intake and energy expenditure. Empirical evidence for the US suggests that caloric expenditure has not changed significantly since 1980, while calories consumed have risen markedly (Cutler et al. (2003)). In line with this, we suppose that the caloric expenditure is constant and normalised to zero. Thus, in our model weight gain is associated with an increase in the consumption of unhealthy food.

Each time period the consumer faces a trade-off: healthy food is better in the long run, however it has a higher cost today. Following the standard economic modeling approach of endowing the consumer with an utility function we recreate this trade-off. In particular, we assume that the utility function of the consumer at period t is given by

$$u\left(\{x^k\}_0^t, 1 - x^t\right) = v\left(D\left(\{x^k\}_0^t, 1 - x^t\right)\right) + m - p_x x^t - p_{1-x}(1 - x^t).$$

where $\{x^k\}_0^t$ is the sequence of present and past consumption of unhealthy food. The function D is an aggregation of present and past consumption of unhealthy food. We assume D is given recursively by

$$D\left(\{x^k\}_0^t, 1 - x^t\right) = \frac{1 - \gamma x^t + \gamma D\left(\{x^k\}_0^{t-1}, 1 - x^{t-1}\right)}{1 + \gamma}$$

The function D is convenient for two reasons. First, it captures the effect of past consumption of unhealthy food and the current consumption of unhealthy food on current utility (or the trade-off between present and future consumption). To be more precise, at time t past consumption of unhealthy food negatively affects current utility through the term $\gamma D\left(\{x^k\}_0^{t-1}, 1 - x^{t-1}\right)$, and the present consumption of unhealthy food also affects current utility via the term $-\gamma x^t$. Second, D is analytically tractable and easy to interpret. Indeed, if the consumption of unhealthy food has always been x, i.e. $\{x^k\}_0^t = \{x\}_0^t$, then the function D has a simple expression: $D\left(\{x^k\}_0^t, 1 - x^t\right) = 1 - \gamma x$. Note that at any point in time consuming unhealthy food is more attractive than consuming healthy food if and only if $v'\frac{\gamma}{1+\gamma} < p_{1-x} - p_x$.

Denote by $D(x^0, 1 - x^0)$ the consumers' initial diet and it is set to a value in $[0, 1]$. The parameter $\gamma \in [0, 1]$ captures the effects of unhealthy food past consumption and also the effect of current unhealthy food consumption. The parameter γ represents the characteristics of the consumer in terms of genetics, etc. This means that, for a given amount of unhealthy food consumption, a consumer with a high γ derives less utility than other consumer with a lower γ.

The function v represents the effects of a certain diet on the consumer's utility. The function v is differentiable with $v' > 0$, $v'' \geq 0$. If $v'' > 0$ then there is habit formation as we discuss in detail in section 3.4. The parameter $m > 0$ represents the agent's endowment, and p_x, p_{1-x} with $0 < p_x < p_{1-x}$, are the prices of the unhealthy and healthy food respectively.

Each period t the consumer maximises the discounted sum of future utility by choosing a sequence $\{x^k\}_{k=t}^\infty$ with $x^k \in [0, 1]$ for all $k \geq t$. If we disregard the constant terms the consumer's problem at time t is

$$\max_{\{x^k\}_{k=t}^\infty} \quad \sum_{i=t}^\infty \delta^{i-t}\left[v\left(D\left(\{x^k\}_0^i, 1 - x^i\right)\right) + (p_{1-x} - p_x)x^t\right]$$

where $\delta \in [0, 1]$ is the discount factor. The trade-off in the consumer's maximisation problem is clear: unhealthy food negatively affects consumer's future utility through the function v, yet in the current period unhealthy food is cheaper than healthy food.

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Notice that the consumer faces exactly the same problem at every t, hence it suffices to solve it for any arbitrary period t. For notational convenience define

$$U^t = \sum_{i=t}^{\infty} \delta^{i-t} \left[v \left(D \left(\{x^k\}_0^i, 1 - x^i \right) \right) + (p_{1-x} - p_x) x^t \right].$$

3.3 A Simple Case

As an initial step to understand individual behaviour, we study a particular case of our model where v is the identity function ($v(D) = D$). If v is the identity function then utility is linear in the consumption of unhealthy food, hence there is no habit formation. In other words, the consumption of unhealthy food in the present period does not affect the marginal utility of consuming unhealthy food in future periods.

If we compute the partial derivative with respect to any x^k at a given t, we obtain

$$\frac{\partial U^t}{\partial x^k} = \delta^{k-t} \left(p_{1-x} - p_x - \frac{\gamma}{1 + \gamma(1 - \delta)} \right).$$

We have the following result.

Proposition 6. *Assume that v is the identity function. The diet that maximises the discounted sum of utility is given by $\{x^k\}_{k=t}^{\infty} = \{x\}_{k=t}^{\infty}$ with*

$$x = \begin{cases} 1 & \text{if } p_{1-x} - p_x - \frac{\gamma}{1+\gamma(1-\delta)} > 0, \\ 0 & \text{if } p_{1-x} - p_x - \frac{\gamma}{1+\gamma(1-\delta)} < 0, \\ r & \text{otherwise} \end{cases}$$

for all $r \in [0, 1]$.

According to Proposition 6, the agent's optimal long run diet is to consume only unhealthy (healthy) food when the price difference between healthy and unhealthy food $(p_{1-x} - p_x)$ is greater (smaller) than the discounted effect of unhealthy food consumption on future utilities $\frac{\gamma}{1+\gamma(1-\delta)}$.

3.4 Habit Formation

In this Subsection and henceforth we assume $v'' > 0$. This means that increasing the consumption of unhealthy food in the current period increases the future return of consuming unhealthy food. Similarly, increasing the consumption of healthy food in the current period increases the future return of consuming healthy food. Therefore, if a consumer increases her current consumption of unhealthy food then she is more likely to increase it even more in the future, and similarly if she increases the consumption of healthy food in the current period.

Notice that the strength of habits is implicit in the functional form of v. In this Subsection we keep a general functional form for v whilst in the next section we parametrised and calibrate the model.

Take any arbitrary period t. Since for all $\{x^k\}_0^{t-1}$ it is true that $D\left(\{x^k\}_0^{t-1}, 1 - x^{t-1}\right) \in [0,1]$ for any $\gamma \in [0,1]$, there exists a $\bar{x}^{t-1} \in [0,1]$ such that $D\left(\{x^k\}_0^{t-1}, 1 - x^{t-1}\right) = 1 - \gamma \bar{x}^{t-1}$. Notice that if past consumption has always been x, i.e. $\{x^k\}_0^{t-1} = \{x\}_0^{t-1}$, then $D\left(\{x^k\}_0^{t-1}, 1 - x^{t-1}\right) = 1 - \gamma x$. Thus, we can interpret $\bar{x}^{t-1}$ as the weighted average diet the consumer has followed in the past up to $t - 1$.

Using this definition and disregarding the constant terms, we can rewrite the maximisation problem at time t as

$$\max_{\{x^k\}_{k=t}^{\infty}} \quad \sum_{i=t}^{\infty} \delta^{i-t} \left[v\left(\frac{1 - \gamma x^i + \gamma(1 - \gamma \bar{x}^{i-1})}{1 + \gamma} \right) + (p_{1-x} - p_x) x^t \right]. \qquad (3.1)$$

We have the following result.

Proposition 7. *Let $\bar{x} \in \mathbb{R}$ be such that*

$$v\left(\frac{1 + \gamma(1 - \gamma\bar{x})}{1 + \gamma} \right) - p_{1-x} \quad = \quad v\left(\frac{1 - \gamma + \gamma(1 - \gamma\bar{x})}{1 + \gamma} \right) - p_x.$$

The diet $\{x^k\}_{k=t}^{\infty} = \{x\}_{k=t}^{\infty}$ that maximises the discounted sum of utility is given

by

$$
x = \begin{cases} 0 & \text{if } \bar{x}^{t-1} < \bar{x} \text{ or } \delta \text{ is sufficiently high} \\ 1 & \text{if } \bar{x}^{t-1} > \bar{x} \text{ and } \delta \text{ is not sufficiently high.} \end{cases}
$$

Proposition 7 states that a consumer would follow a healthy diet if and only if either she is used to eat healthy or if she is patient enough with respect to future consumption. Notice that the proposition gives no explicit equation of either $\bar{x}$ nor $\bar{\delta}$. These two values depend on the specific function v and the value of the parameters and, thus, are computed when we calibrate and simulate the model.

In principle the value of $\bar{x}$ could be outside the interval $[0, 1]$. If $\bar{x} < 0$, the consumer follows a healthy diet regardless of her past consumption and discount factor. On the other hand, if $\bar{x} > 1$ then whether the consumer follows a healthy diet or not depends on her discount factor.

Notice that proposition 7 states that a consumer either purchases only unhealthy food or only healthy food. This is a direct consequence of assuming that only one unit of food is consumed per period and that $v'' > 0$. This dichotomous result poses no problem for interpreting the model, rather the opposite, it makes interpretation easier. The link between the healthiness of the diet chosen by the consumer and her weight in this framework is as follows. When the consumer chooses to eat unhealthy $(x = 1)$ we consider she is overweight. On the other hand, when the consumer chooses to eat healthy $(x = 0)$ she is not overweight. This simplifies the interpretation in our model when we introduce a population of consumers (next subsection), so different agents will choose different diets with $x \in \{0, 1\}$. Therefore, on aggregate a certain percentage of the population will eat unhealthy and be overweight, and the rest of the population will eat healthy and not be overweight.

3.5 Policy Discussion

In order to study the effect of different policies on the unhealthy food consumption in a population, we assume that consumers differ in their parameter γ. As already mentioned, the parameter γ is meant to capture characteristics such as lifestyle, genetics, peer effect, etc. Hence, a population with a higher average γ can be interpreted as a society that is more concerned towards its well being and how it looks, exercise regularly, their bodies deal better with the consumption of unhealthy food, has been historically more inclined towards healthier foods, etc. In order to simplify the calculations we keep constant across agents the discount factor δ and the functional form of v.

The three policies we consider in this chapter are a tax, a subsidy and cash incentives. A tax is represented in the model by an increase in the price of unhealthy food from p_x to $p_x(1 + t)$, where t is the size of the tax. Similarly, a subsidy is represented by a decrease in the price of healthy food from p_{1-x} to $p_{1-x}(1 - s)$, where s is the size of the subsidy. Finally, cash incentives consists of a monetary reward of I whenever the individual consumes healthy food. That is, with cash incentives we add to the utility of the consumer, U^t, the term $\sum_{i=t}^{\infty} \delta^{i-t} 1_{x^t} I$ where 1_{x^t} equals 1 if $x^t = 0$ and 0 otherwise.

All three policies can reduce the population's consumption of unhealthy food and, therefore, they may have a permanent effect even if the policy is applied only temporarily. This can happen because by changing the optimal decision of a consumer at a certain point in time her habits change and, thus, it is possible to also affect her future decisions. More specifically, consider a consumer who finds it is optimal to choose the unhealthy diet. Therefore, by proposition 7 we must have that $\bar{x}^{t-1} > \bar{x}$. When policy $P \in \{t, s, I\}$ is implemented, if we let $\bar{x}(P)$ be the value of $\bar{x}$ in proposition 7 when such policy is introduced, then given that $v', v'' > 0$ we have $\bar{x}(t), \bar{x}(s), \bar{x}(I) < \bar{x}$. Therefore, we could have that $\bar{x}^{t-1} < \bar{x}(P)$ with $P \in \{t, s, I\}$ and the consumer chooses the healthy diet when a policy is introduced. If this happens, then it is possible that a consumer moves from a situation where $\bar{x}^{t-1} > \bar{x}$ to a

situation where $\bar{x}^{T+t-1} < \bar{x}$ after the policy P has been in place for T periods. From time $T + t$ on, the consumer follows the healthy diet even if the policy is removed.

In this respect, it is worth noticing the difference between our setting and that of Becker and Murphy (1988) in terms of policy implications. In Becker and Murphy (1988) addicts respond more to permanent than to temporary changes in the prices of addictive goods. In this chapter, on the contrary, a temporary policy that is able to change the consumer's habits can be as effective as a permanent one.

3.5.1   Calibration

In this subsection we calibrate the model and simulate the effects of the three different policies for the US and the UK.

We assume that the population is such that γ, the parameter that represents individual characteristics, follows a normal distribution truncated between 0 and 1. We write this as $\gamma \sim N_{[0,1]}(\mu, \sigma^2)$, where as customary μ is the mean and σ^2 is the variance. We set $\sigma^2 = 0.1$ and consider three different possible values for the mean, $\mu \in \{0, 0.5, 1\}$.

The initial consumption of unhealthy food, x^0, is random and equal to either 0 or 1. We use a Bernoulli distribution and set at random $x^0 = 1$ for 68% of the population and $x^0 = 0$ for 32% of the population in the case of the US, and $x^0 = 1$ for 57% of the population and $x^0 = 0$ for 43% of the population in the case of the UK. These values correspond to the WHO estimates whereby 68% of the US population and 57% of the UK population is overweight.[6]

Each time period is set equal to a quarter and the discount factor is assumed to take the value $\delta = 0.987$. Given that each time period represents a quarter, we have that $0.987^4 = 0.949$, which is in line with current studies where the annual discount rate is found to be around 0.95 (see for instance Laibson et al. (2008)).

Since each time period is a quarter, the prices p_x and p_{1-x} represent the quarterly spending on unhealthy and healthy food respectively. If a proportion y of the

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[6]We remind the reader that according to the WHO a person is overweight if her BMI is equal or above 25. Note that obese people ($BMI \geq 30$) are also overweight.

population is overweight and e is the quarterly expenditure on food of an average consumer we have that

$$e \;=\; yp_x + (1-y)p_{1-x}.$$

Monsivais et al. (2010) estimate that the ratio between the price of healthy food and unhealthy food is between 1 and 8.3, depending on the nutrient density of the food under consideration. Using the fact that in our model all consumers purchase the same amount of food per period we focus on an intermediate value for this ratio and set $4.5p_x = p_{1-x}$. Thus,

$$p_x \;=\; \frac{e}{y + 4.5(1-y)}. \tag{3.2}$$

For the US, using data from the Bureau of Labor Statistics[7] we obtain that $e = \$1,610.75$. According to the WHO the proportion of overweight people in the US is $y = 0.68$. Hence, if we harmonise to 2010 US dollars[8], we have that $p_x(US) = \$769.50$ and $p_{1-x}(US) = \$3,462.76$.

For the UK, the quarterly food spending is £659.10.[9] According to the WHO the proportion of overweight people in the UK is $y = 0.57$. Hence, if we harmonise to 2010 British pounds[10], we have that $p_x(UK) = £277.65$ and $p_{1-x}(UK) = £1,249.41$.

We assume the function v to be such that

$$v\left(D\right) \;=\; N(D^n)$$

where the exponent $n > 1$ and the scaling factor $N > 0$ are free parameters and their values are set to match the data of the country under consideration. In particular, we are looking at values of n and N such that two conditions are satisfied. First, in the absence of any policy the percentage of consumers choosing the unhealthy

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[7]Consumer Expenditures in 2008, U.S. Bureau of Labor Statistics.
[8]CPI index, U.S. Bureau of Labor Statistics.
[9]Living Costs and Food Survey 2008, Office for National Statistics.
[10]CPI index, Office for National Statistics.

diet equals 68% for the US and 57% for the UK. Second, amongst these consumers whose optimal consumption can be changed from the unhealthy diet to the healthy one, i.e. consume $x = 1$ but would consume $x = 0$ if their diet had been healthy in the past $(x^0 = 0)$, the maximum number of quarters needed for such a change is six (a year and a half). We have found no empirical reference for the average time it takes for an overweight person to achieve a BMI below 25. Nevertheless, medical literature suggests that a key challenge in weight loss interventions is to both attain initial weight loss and to maintain that weight loss over periods of 12 months or more (Volpp et al. (2008)).[11]

Using the values of δ, p_x, p_{1-x} and the distribution $\gamma \sim N_{[0,1]}(\mu, \sigma^2)$ with $\sigma^2 = 0.1$ and $\mu \in \{0, 0.5, 1\}$, we find that a habit parameter of $n = 50$ and scaling factors of $N = 2740$ for the US and $N = 990$ for the UK fulfil our two desired requirements.[12] Notice that the calibrated habit parameter, $n = 50$, is in line with the literature supporting addiction to calories from food. Indeed, Richards et al. (2007) show empirical evidence of strong addiction to carbohydrates, and Liu and Lopez (2009) provide evidence that carbonated soft drinks are rationally addictive.

With respect to the different policies, we consider the value of the tax and the subsidy fixed at 10%. This value is greater than the 1.5% to 7.25% soft drink and snack food tax applied in different US states (Jacobson and Brownell (2000)). We choose a higher tax (and subsidy) given that, as argued by Jacobson and Brownell (2000), current tax levels are too small to affect unhealthy food consumption.

When considering cash incentives, we assume that the amount of money given to each consumer per quarter equals to the difference between the quarterly cost of consuming healthy food and the quarterly cost of consuming unhealthy food. This ensures that all consumers find it optimal to follow a healthy diet for at least as long as the policy lasts. Given the numerical values derived above, we have that the

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[11]Moreover, we have run numerical simulations where the maximum number of quarters needed for changing the consumer's habits is either five or seven and found that results are very similar to those obtained when such number equals six. However, the effectiveness of cash incentives seems to depend slightly negatively on the number of quarters considered.

[12]We stress here that neither N nor the strength of the habit parameter n are chosen freely, their values are calibrated using the data described above.

quarterly amount of cash given must equal $2,693.26 in case of the US and £971.76 in case of the UK. We could assume instead that each consumer receives exactly the amount of cash needed to have the healthy diet as optimal choice. However, this poses a problem from the applied policy point of view because it may not be possible or feasible to discriminate amongst consumers. Similarly, it may be difficult to monitor consumers to ensure they are consuming healthy food. Nevertheless, this could be implemented by regular weight and BMI checks with their GPs.

The costs of implementing each policy are calculated as follows. We assume that taxing unhealthy food has no implementation costs. The cost of implementing the subsidy is given by the amount of the subsidy itself. The cost of implementing cash incentives equals the amount of cash to be given per quarter to each consumer times the number of quarters needed to change the habits of the consumer being targeted. We assume that cash incentives are given only to those consumers who can successfully change their unhealthy habits.

The benefit of each policy is calculated by looking at the expense that does not occur if a particular policy is implemented (avoidable costs). In our model, the avoidable cost is the money that the security system saves because of the reduction in the number of overweight people. In the case of a tax, in addition to the avoidable costs the revenue from the tax is also considered as a benefit.

Each policy has the added benefit that it increases the utility of the population. Both whilst the policy is in place because of the subsidy or the monetary rewards and also in the long term because of the decrease in unhealthy food consumption. We have chosen not to consider the increase in utility as a benefit for the society for several reasons. First, we would be adding utility to money, which makes no sense from the methodological point of view even though the utility function assumed is quasi-linear in wealth. Second, we would need to aggregate the utilities of different consumers. Finally and most importantly, we want to take the conservative approach of focusing only on the monetary benefits of each policy instead of the social ones.

To calculate the amount of money the social security system saves per overweight

patient we proceed as follows. The total saving per overweight patient is equal to the total cost per overweight patient (avoidable cost). The total cost per overweight patient is equal to the cost per overweight patient per year times the number of years each overweight patient receives medical treatment. Notice that we consider that the additional cost that an overweight patient imposes on the social security system when compared to a non-overweight patient.

In the US, the cost to Medicare per overweight patient per year is, on average, \$600.00 extra when compared to a non-overweight patient (Finkelstein et al. (2009)).[13] We consider that patients enter Medicare at the age of 65 and live for an average of 77 years minus 3 years for being overweight.[14] Thus, if we harmonise to 2010 US dollars and assume an annual interest rate of 3%, then each overweight person costs Medicare on average \$5,318.67.

In the UK, there is no evidence of the additional cost to the NHS of an overweight patient compared to a normal weight patient. The approach we take is to calculate the additional cost of an overweight patient for the NHS as the ratio between the total overweight cost and the number of overweight patients for the NHS. Since we do not have information on the number of overweight patients at the NHS we use instead the number of overweight people in the country.[15] The costs to the NHS attributable to overweight patients equals £5,146 million per year[16] and the number of overweight people in the UK in 2008 was 35.00 million (WHO). Therefore, the cost per overweight patient is £147.04 per year. For the number of years each overweight patient receives medical treatment we consider that overweight people start receiving NHS attention at the age of 59[17] and live for an average of 77 years minus 3 years for being overweight. Thus, if we harmonise to 2010 British pounds and assume an annual interest rate of 3% each overweight person costs the NHS on

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[13]Measured in 2008 US dollars. We found no data on overweight only patients (BMI between 25 and 30).

[14]Moderate Obesity Takes Years Off Life Expectancy, University of Oxford (2009, March 20).

[15]This is a sensible assumption because all UK residents have the right to NHS treatment.

[16]Measured in 2007 British pounds (Scarborough et al. (2011)).

[17]We do not have information on the average age overweight people start receiving NHS attention. However, it was communicated to us by a NHS official in the Leicestershire Nutrition and Dietetic Service that the average age in their NHS weight loss groups is about 59 years old.

average £2,067.21.

The calibration we just carried out is summarised in table 3.1.

Table 3.1: Calibration

γ	$\sim N_{[0,1]}(\mu, \sigma^2)$
μ	$\in \{0, 0.5, 1\}$
σ^2	0.1
t	quarter
x_0	Bernoulli(0.68) (US), Bernoulli(0.57) (UK)
δ	0.987
p_x	\$769.50 (US), £277.65 (UK)
p_{1-x}	\$3,462.76 (US), £1,249.41 (UK)
$v(D)$	$N(D^n)$
N	2740 (US), 990 (UK)
n	50
tax	10%
subsidy	10%
cash incentives	\$2,693.26 (US), £971.76 (UK)
S.S. costs per overweight	\$5,318.67 (US), £2,067.21 (UK)

3.5.2 Numerical Results

We simulate the model for both the US and the UK and the three different policies for a population of 100 consumers and then scale up the results to a population of 304.37 million in the case of the US and a population of 61.40 million in the case of the UK.[18] We proceed in this way so simulating the model is computationally more convenient.

Tables 3.2 and 3.3 show the results of the simulations of our model given the calibration just described. By looking at both tables, we can conclude that:

1. Cash incentives is the most effective policy in reducing unhealthy food consumption.

2. However, cash incentives is the least profitable policy and can lead to significant monetary costs.

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[18]Population in 2008, US Census Bureau (US) and Office for National Statistics (UK).

3. Taxes are relatively ineffective in reducing unhealthy food consumption.

4. Subsidies is the most profitable policy and relatively effective in reducing unhealthy food consumption.

Table 3.2: Policy Comparison (US)

	$\mu = 0$	$\mu = 0.5$	$\mu = 1$
Overweight no policy (%)	68	68	68
Tax			
Overweight with policy (%)	36	57	68
Revenue	8,432	13,350	15,927
Benefit	513,181	178,076	0
Benefit + Revenue	521,613	191,426	15,927
Subsidy			
Overweight with policy (%)	13	8	18
Subsidies	91,696	96,966	86,426
Benefit	887,140	971,321	809,434
Benefit - Cost	795,444	874,355	723,008
Cash Incentives			
Overweight with policy (%)	21	1	1
Periods needed p.p. (average)	1.77	3.33	4.75
Cost	677,522	1,828,089	2,606,856
Benefit	757,630	1,084,642	1,084,642
Benefit - Cost	80,108	-743,447	-1,522,214

2010 million US dollars unless stated otherwise. Revenue: Money collected from the tax. Benefit: Avoidable cost to Medicare. Subsidies: Expense for subsidising healthy food. Periods needed p.p. (average): Average number of periods per person during which beneficiaries of cash incentives receive the monetary payment. Cost: Total amount of money given to beneficiaries of cash incentives.

Cash incentives is the most effective policy to reduce the number of people with unhealthy diets. This result is due to the fact that, given the discount factor and the presence of habit, most consumers' behaviour depend on their initial diets. Hence, given that most consumers initially choose unhealthy diets, motivating healthy food consumption via cash incentives has a significant positive effect on the aggregate level of unhealthy food consumption.

The reason behind the ineffectiveness of a tax is because, given the differences in prices between healthy and unhealthy food, a 10% change in the cost of unhealthy

Table 3.3: Policy Comparison (UK)

	$\mu = 0$	$\mu = 0.5$	$\mu = 1$
Overweight no policy (%)	57	57	57
Tax			
Overweight with policy (%)	34	48	57
Revenue	580	818	972
Benefit	29,192	11,423	0
Benefit + Revenue	29,772	12,241	972
Subsidy			
Overweight with policy (%)	13	7	18
Subsidies	6,674	7,134	102
Benefit	55,846	63,461	49,500
Benefit - Subsidies	49,172	56,327	49,397
Cash Incentives			
Overweight with policy (%)	21	1	1
Periods needed p.p. (average)	1.89	3.00	4.74
Cost	40,636	100,236	158,266
Benefit	45,692	71,077	71,077
Benefit - Cost	5,056	-29,159	-87,189

2010 million pounds unless stated otherwise. Revenue: Money collected from the tax. Benefit: Avoidable cost to NHS. Subsidies: Expense for subsidising healthy food. Periods needed p.p. (average): Average number of periods per person during which beneficiaries of cash incentives receive the monetary payment. Cost: Total amount of money given to beneficiaries of cash incentives.

food has a small absolute effect. To illustrate this point, note that a 10% tax increases the quarterly cost of unhealthy food by $76.95 in the US and £27.77 in the UK, while a 10% subsidy reduces the quarterly cost of healthy food by $346.28 in the US and £124.94 in the UK.

Cash incentives are relatively costly and can lead to significant monetary costs. This is specially relevant in the US, where cash incentives, although very effective in reducing unhealthy food consumption, can lead to a net long term expense of $1,522,214 million. The reason for this lies in the differences between both countries' social security systems. In the US an overweight person will generate costs to the public sector during 9 years, while in the UK an overweight person generates such costs during 15 years. This explains why the monetary benefits for the public sector for reducing unhealthy food consumption are greater in the UK than in the US.

Finally, although higher values of μ imply higher long term loss in utility from eating unhealthy, higher values of μ also make it harder to change from an unhealthy diet to a healthy one. This is the reason why there is a non-monotonic relation between μ and the total consumption of unhealthy food when subsidies are considered. We not always observe such non-monotonicity when the tax is considered because, as already argued, its absolute effect is lower than that of the subsidy.

3.5.3   Obese Population

A reasonable question is whether we obtain the same results when only obese people are considered. That is, if we regard consumers whose BMI is between 25 and 30 as not following an unhealthy diet. This is the object of study in this subsection.

The parameters γ, μ, σ^2, t and δ are set to the same values as the ones used in the previous calibration. According to the WHO, 34% of the US population and 21% of the UK population is obese. According to this information we set at random $x^0 = 1$ for 34% of the population and $x^0 = 0$ for 66% of the population in the case of the US, and $x^0 = 1$ for 21% of the population and $x^0 = 0$ for 79% of the population in the case of the UK.

Using equation (3.2), the fact that $e = \$1,610.75$ for the US and £659.10 for the UK, and $y = 0.34$ for the US and $y = 0.21$ for the UK, we obtain that $p_x(US) = \$491.81$ and $p_{1-x}(US) = \$2,213.16$, and $p_x(UK) = £184.73$ and $p_{1-x}(UK) = £831.28$ (all values harmonised to 2010 prices). Note that in this case p_x and p_{1-x} represent the quarterly costs of following a diet that will lead to a person being obese and the quarterly costs of following a diet that would lead to a person not being obese, respectively.

As in Subsection 3.5.1, values of n and N are identified such that the percentage of consumers choosing the unhealthy diet equals 34% for the US and 21% for the UK, and the maximum number of quarters needed for a consumer to change her habits equals six. Using the values of δ, p_x, p_{1-x} and the distribution $\gamma \sim N_{[0,1]}(\mu, \sigma^2)$, a habit parameter of $n = 50$ and scaling factors of $N = 1770$ for the US and $N = 668$

for the UK fulfil the two requirements.

With respect to the different policies under analysis, the same values are used as those employed in the previous calibration except for two variables: cash incentives and social security benefits in the UK. Given the numerical values derived above, the quarterly amount of cash given must equal $1,721.35 in case of the US and £646.55 in the case of the UK. Moreover, taking into account that the number of obese people in the UK in 2008 was 12.89 million[19], then each obese person costs the NHS on average £2,507.83. Note that for the US we assume each obese Medicare patient costs $5,318.67, which is the same value used in the previous calibration.

The calibration when only obese consumers are considered is presented in table 3.4.

Table 3.4: Calibration, Obese Only

γ	$\sim N_{[0,1]}(\mu, \sigma^2)$
μ	$\in \{0, 0.5, 1\}$
σ^2	0.1
t	quarter
x_0	0.34 (US), 0.21 (UK)
δ	0.987
p_x	$491.81 (US), £184.73 (UK)
p_{1-x}	$2,213.16 (US), £831.28 (UK)
$v(D)$	$N(D^n)$
N	1,770 (US), 668 (UK)
n	50
tax	10%
subsidy	10%
cash incentives	$1,721.35 (US), £646.55 (UK)

As before, we simulate the model and the three different policies for a population of 100 consumers and then scale up the results to a population of 304.37 million in the case of the US and 61.40 million in the case of the UK. Tables 3.5 and 3.6 show the results of the simulations.

By comparing tables 3.2 and 3.3 with tables 3.5 and 3.6 it is clear that subsidies

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[19]Calculated as the percentage of obese people for UK in 2008 (WHO) to the population of the UK in mid-2008 (Office of National Statistics).

Table 3.5: Policy Comparison (US), Obese Only

	$\mu = 0$	$\mu = 0.5$	$\mu = 1$
Obese no policy (%)	34	34	34
Tax			
Obese with policy (%)	21	28	32
Revenue	3,144	4,191	4,790
Benefit	210,453	97,132	32,377
Benefit + Revenue	213,596	101,324	37,168
Subsidy			
Obese with policy (%)	7	2	3
Subsidies	62,648	66,016	65,342
Benefit	437,094	518,038	501,849
Benefit - Subsidies	374,447	452,022	436,507
Cash Incentives			
Obese with policy (%)	13	5	1
Periods needed p.p. (average)	1.62	3.00	4.03
Cost	178,133	455,823	696,833
Benefit	339,962	469,472	534,227
Benefit - Cost	161,830	13,648	-162,607

2010 million US dollars unless stated otherwise. Revenue: Money collected from the tax. Benefit: Avoidable cost to Medicare. Subsidies: Expense for subsidising healthy food. Periods needed p.p. (average): Average number of periods per person during which beneficiaries of cash incentives receive the monetary payment. Cost: Total amount of money given to beneficiaries of cash incentives.

are now the most effective policy in reducing the number of people with unhealthy diets. This is because the difference between p_x and p_{1-x} when only obese people are considered is smaller than the price difference when overweight people are considered. This implies that the effects of a 10% subsidy are more acute.

Given that the difference between p_x and p_{1-x} when considering obese people is smaller than with overweight people, the cost of cash incentives is also smaller with only obese people. This is the reason why the ratio of effectiveness of cash incentives (number of people with unhealthy diets) to their implementation costs is higher.

The calibration and simulation of the model when only obese consumers are considered enforces the idea that subsidies seem the best alternative to solve the obesity problem.

Table 3.6: Policy Comparison (UK), Obese Only

	$\mu = 0$	$\mu = 0.5$	$\mu = 1$
Obese no policy (%)	21	21	21
Tax			
Obese with policy (%)	13	19	21
Revenue	147	214	237
Benefit	12,318	30,080	0
Benefit + Revenue	12,465	3,294	237
Subsidy			
Obese with policy (%)	5	2	1
Subsidies	4,849	5,002	5,053
Benefit	24,636	29,255	30,795
Benefit - Subsidies	19,787	24,254	25,742
Cash Incentives			
Obese with policy (%)	15	5	1
Periods needed p.p. (average)	1.67	3.06	3.95
Cost	3,970	19,452	31,361
Benefit	9,239	24,636	30,795
Benefit - Cost	5,268	5,185	-565

2010 million pounds unless stated otherwise. Revenue: Money collected from the tax. Benefit: Avoidable cost to NHS. Subsidies: Expense for subsidising healthy food. Periods needed p.p. (average): Average number of periods per person during which beneficiaries of cash incentives receive the monetary payment. Cost: Total amount of money given to beneficiaries of cash incentives.

3.5.4 Alternative Social Security Costs (US)

In a recent paper Cawley and Meyerhoefer (2012) provide an alternative measure of the marginal effect of obesity on medical care costs. They find that an obese person raises medical expenditures by $2,418 (in 2005 US dollars) relative to a non-obese person. Cawley and Meyerhoefer suggests that previous literature has underestimated the medical costs of obesity and, therefore, the economic rationale for government intervention to reduce obesity-related externalities. Table 3.7 shows the result of the simulations of our model considering the alternative obesity cost estimated by Cawley and Meyerhoefer (2012).

As it can be seen in table 3.7, most of our previous conclusions are still valid. The only difference is that with higher costs per obese person cash incentives no

longer lead to a deficit in the social security budget. This is simply caused by the fact that now the benefits of reducing obesity are more acute. Nevertheless, we still find that subsidies are the most cost-effective policy.

Table 3.7: Policy Comparison (US), Obese Only - alternative cost

	$\mu = 0$	$\mu = 0.5$	$\mu = 1$
Obese no policy (%)	34	34	34
Tax			
Obese with policy (%)	21	28	32
Revenue	3,144	4,191	4,790
Benefit	934,992	431,535	143,845
Benefit + Revenue	938,135	435,726	148,635
Subsidy			
Obese with policy (%)	7	2	3
Subsidies	62,648	66,016	65,342
Benefit	1,941,906	2,301,518	2,229,596
Benefit - Subsidies	1,879,258	2,235,502	2,164,254
Cash Incentives			
Obese with policy (%)	13	5	1
Periods needed p.p. (average)	1.62	3.00	4.03
Cost	178,133	455,823	696,833
Benefit	1,510,371	2,085,751	2,373,441
Benefit - Cost	1,332,239	1,629,927	1,676,607

2010 million US dollars unless stated otherwise. Revenue: Money collected from the tax. Benefit: Avoidable cost to Medicare. Subsidies: Expense for subsidising healthy food. Periods needed p.p. (average): Average number of periods per person during which beneficiaries of cash incentives receive the monetary payment. Cost: Total amount of money given to beneficiaries of cash incentives.

3.5.5 Policy Recommendations

Upon analysis the results suggest that subsidies are superior to taxes because subsidies are both more effective in reducing unhealthy food consumption and produce higher long term monetary benefits to the society. Therefore governments should put their efforts into subsidising healthy food rather than taxing unhealthy food as many countries are currently doing.

Cash incentives is in most circumstances the best policy to reduce unhealthy food consumption but it is an expensive alternative; cash incentives can lead to

very significant long term losses for the government. Although subsidies are not as effective as cash incentives, subsidies can significantly reduce unhealthy food consumption and provide the highest monetary benefits to the society. In our analysis no reference nor claim is made regarding potential non-monetary benefits of having a healthier population. Thus, although cash incentives potentially lead to considerably monetary expenses and a deficit in the social security budget, it could be the case that the non-monetary benefits of this policy off-set or justify its implementation. That is an ethical and political issue that is not for us to discuss.

3.6 Conclusion

To handle the obesity problem governments have responded with a variety of interventions: product taxes, banning private advertising of foods that are high in fat, salt and sugar, promoting advertising of the consequences of unhealthy food consumption, banning sale of highly sugar-filled products in public schools, etc. Currently there is a discussion regarding cash incentives being used to promote healthy behaviour. Within this context, we addressed the following questions: are taxes, subsidies or cash incentives effective to reduce unhealthy food consumption? If so, which is the most appropriate policy to tackle the obesity problem?

Our results suggest that cash incentives can be the most effective policy in reducing unhealthy food consumption. However, when we compare the benefits due to the reduction in costs for the social security system and the implementation costs of the policy, cash incentives can lead to significant monetary losses. Taxes are relatively ineffective in reducing unhealthy food consumption. Finally, we found that subsidies have the best balance between effectiveness and monetary benefits to the society.

This chapter contributes to the economic analysis of unhealthy food consumption and to the public debate on how to tackle the obesity problem. This chapter is novel as within this topic we built, calibrated and simulated a theoretical model

to US and UK data, thus quantifying the effects of the different policies. There are several issues left for possible future research, for instance considering hyperbolic discounting or assuming a non-separable utility function amongst other. Nevertheless, this chapter sheds new light on the issue of how to tackle the obesity problem by suggesting subsides rather than taxes or cash incentives, as a potential solution.

Chapter 4

Appendix

4.1 Proofs Chapter 1

Lemma 1.

Proof. Part *(a)*. Suppose the incumbent chooses $t_I = D$. The conditions such that $t_E = D$ is the best response when the entrant expect the incumbent chooses D are the following:

(i) $\Pi_E(D, D) > \Pi_E(A, D)$ if $(\mu - 1)k > \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$.

(ii) $\Pi_E(D, D) > \Pi_E(Out, D)$ if $\frac{\alpha}{2} - k > F$.

Part *(b)*. Suppose the incumbent chooses $t_I = D$. The conditions such that $t_E = A$ is the best response when the entrant expect the incumbent chooses D are the following:

(i) $\Pi_E(D, D) < \Pi_E(A, D)$ if $(\mu - 1)k < \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$.

(ii) $\Pi_E(A, D) > \Pi_E(Out, D)$ if $\frac{\alpha}{2} + \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha} - \mu k > F$.

Part *(c)*. Suppose the incumbent chooses $t_I = D$. The conditions such that $t_E = Out$ is the best response when the entrant expect the incumbent chooses D are the following:

(i) $\Pi_E(D, D) < \Pi_E(D, Out)$ if $\frac{\alpha}{2} - k < F$.

(ii) $\Pi_E(A, D) < \Pi_E(Out, D)$ if $\frac{\alpha}{2} + \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha} - \mu k < F$.

Part *(d)*. Suppose the incumbent chooses $t_I = A$. The conditions such that $t_E = D$ is the best response when the entrant expect the incumbent chooses A are the following:

(i) $\Pi_E(D, A) > \Pi_E(A, A)$ if $(\mu - 1)k > \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$.

(ii) $\Pi_E(D, A) > \Pi_E(Out, A)$ if $\frac{\alpha}{2} - \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha} - k > F$.

Part *(e)*. Suppose the incumbent chooses $t_I = A$. The conditions such that $t_E = A$ is the best response when the entrant expect the incumbent chooses A are the following:

(i) $\Pi_E(D, A) < \Pi_E(A, A)$ if $(\mu - 1)k < \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$.

(ii) $\Pi_E(A, A) > \Pi_E(Out, A)$ if $\frac{\alpha}{2} - \mu k > F$.

Part *(f)*. Suppose the incumbent chooses $t_I = A$. The conditions such that $t_E = Out$ is the best response when the entrant expect the incumbent chooses A are the following:

(i) $\Pi_E(D, A) < \Pi_E(Out, A)$ if $\frac{\alpha}{2} - \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha} - k < F$.

(ii) $\Pi_E(A, A) < \Pi_E(Out, A)$ if $\frac{\alpha}{2} - \mu k < F$.

$\square$

Proposition 1.

Proof. For parts *(a)* to *(c)*, suppose $\beta(1 - \lambda) < 6\alpha$ (C1). This condition implies that $b_0 < b_2$. Given that $b_0 > b_1$, if C1 holds then $b_1 < b_0 < b_2$.

Part *(a)*. Suppose E chooses $t_E = D$ at the second stage. The conditions such that $t_I = D$ is the best response when the incumbent expects the entrant chooses D is:

$(\mu - 1)k > \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_0)$

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From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = D$ if $(\mu - 1)k > \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_0)$

From Lemma 1 we also have that entrant's best response to $t_I = A$ is $t_E = D$ if $(\mu - 1)k > \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_1)$

Notice that if $\Delta k > b_0$ then $\Delta k > b_1$ also holds.

We also need the conditions such that firms make profits. The entrant makes profits if $\frac{\alpha}{2} - k > F$. The incumbent makes profit if $\frac{\alpha}{2} - k > 0$. Notice that if the entrant makes profits the incumbent also makes profits.

Therefore, $\Delta k > b_0$ is a necessary condition and $\frac{\alpha}{2} - k > F$ is a sufficient condition for $(t_I^*, t_E^*) = (D, D)$.

Part *(b).* Suppose E chooses $t_E = A$ at the second stage. The conditions such that $t_I = A$ is the best response when the incumbent expects the entrant chooses $t_E = A$ is:

$(\mu - 1)k < \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k < b_1)$

From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = A$ if $(\mu - 1)k < \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k < b_0)$

From Lemma 1 we also have that entrant's best response to $t_I = A$ is $t_E = A$ if $(\mu - 1)k < \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k < b_1)$

By assumption C1, $b_1 < b_0 < b_2$. Hence $\Delta k < b_1$ is a necessary condition for $(t_I^*, t_E^*) = (A, A)$.

We also need the conditions such that firms make profits. The entrant makes profits if $\frac{\alpha}{2} - \mu k > F$. The incumbent makes profit if $\frac{\alpha}{2} - \mu k > 0$. Notice that if the entrant makes profits the incumbent also makes profits.

Therefore, $\Delta k < b_1$ and $\frac{\alpha}{2} - \mu k > F$ are necessary and sufficient conditions for $(t_I^*, t_E^*) = (A, A)$.

Part *(c).* From Lemma 1 we have that entrant's best response to $t_I = A$ is $t_E = D$ if

$(\mu - 1)k > \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_1)$

From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = A$ if $(\mu - 1)k < \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. ($\Delta k < b_0$)

Given entrant's best response, the condition such that the incumbent chooses $t_I = A$ is

$(\mu - 1)k < \frac{2\beta(1-\lambda)}{3}$. ($\Delta k < b_2$).

We also need the conditions such that firms make profits. The entrant makes profits if $\frac{\alpha}{2} - b_1 - k > F$. The incumbent makes profit if $\frac{\alpha}{2} + b_0 - \mu k > 0$. Notice that if the entrant makes profits the incumbent also makes profits.

Therefore, $b_1 < \Delta k < b_0$, $\Delta k < b_2$ and $\frac{\alpha}{2} - b_1 - k > F$ are necessary and sufficient conditions for $(t_I^*, t_E^*) = (A, D)$.

Now, I am going to show that the outcome $(t_I^*, t_E^*) = (D, A)$ is not possible under C1.

From Lemma 1 we have that entrant's best response to $t_I = A$ is $t_E = D$ if $(\mu - 1)k > \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. ($\Delta k > b_1$)

From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = A$ if $(\mu - 1)k < \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. ($\Delta k < b_0$)

Given entrant's best response, the condition such that the incumbent chooses $t_I = D$ is $(\mu - 1)k < \frac{2\beta(1-\lambda)}{3}$, that is $\Delta k > b_2$. However, C1 implies that $b_0 < b_2$, hence the optimal condition for the incumbent to choose $t_I = D$ cannot be satisfied.

For parts *(d)* to *(f)*, suppose $\beta(1 - \lambda) > 6\alpha$ (C2). This condition implies that $b_0 > b_2$. Given that $b_0 > b_1$, if C2 holds then $b_1 < b_2 < b_0$. C2 also implies that $b_1 < 0$.

Recall that the outcome $(t_I, t_E) = (A, A)$ requires that $\Delta k < b_1$. However, since $\Delta k > 0$, therefore $(t_I, t_E) = (A, A)$ is not possible under C2.

Part *(d)*. Suppose E chooses $t_E = D$ at the second stage. The conditions such that $t_I = D$ is the best response when the incumbent expects the entrant chooses D is:

$(\mu - 1)k > \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. ($\Delta k > b_0$)

From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = D$ if

$(\mu - 1)k > \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_0)$

From Lemma 1 we also have that entrant's best response to $t_I = A$ is $t_E = D$ if

$(\mu - 1)k > \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_1)$

Notice that if $\Delta k > b_0$ then $\Delta k > b_2$ also holds.

We also need the conditions such that firms make profits. These conditions are the same as in part *(a)*.

Therefore, $\Delta k > b_0$ is a necessary condition and $\frac{\alpha}{2} - k > F$ is a sufficient condition for $(t_I^*, t_E^*) = (D, D)$.

Part *(e)*. From Lemma 1 we have that entrant's best response to $t_I = A$ is $t_E = D$ if

$(\mu - 1)k > \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_1)$

Given C2 implies that $b_1 < 0$, this condition is satisfied for any $\Delta k > 0$.

From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = A$ if

$(\mu - 1)k < \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k < b_0)$

Given entrant's best response, the condition such that the incumbent chooses $t_I = A$ is

$(\mu - 1)k < \frac{2\beta(1-\lambda)}{3}$, that is $\Delta k < b_2$. Given that C2 implies that $b_2 < b_0$, we have that $\Delta k < b_2$ is the binding condition.

The conditions such that firms make profits are the same as in part *(b)*.

Therefore, $\Delta k < b_2$ and $\frac{\alpha}{2} - b_1 - k > F$ are necessary and sufficient conditions for $(t_I^*, t_E^*) = (A, D)$.

Part *(f)*. From Lemma 1 we have that entrant's best response to $t_I = A$ is $t_E = D$ if

$(\mu - 1)k > \frac{\beta(1-\lambda)}{3} - \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k > b_1)$

Given C2 implies that $b_1 < 0$, this condition is satisfied for any $\Delta k > 0$.

From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = A$ if

$(\mu - 1)k < \frac{\beta(1-\lambda)}{3} + \frac{\beta^2(1-\lambda)^2}{18\alpha}$. $(\Delta k < b_0)$

Given entrant's best response, the condition such that the incumbent chooses $t_I = D$ is

$(\mu - 1)k < \frac{2\beta(1-\lambda)}{3}$. $(\Delta k > b_2)$.

We also need the conditions such that firms make profits. The entrant makes profits if $\frac{\alpha}{2} + b_0 - \mu k > F$. The incumbent makes profit if $\frac{\alpha}{2} - b_1 - k > 0$. Notice that if the entrant makes profits the incumbent also makes profits.

Therefore, $b_2 < \Delta k < b_0$ and $\frac{\alpha}{2} + b_0 - \mu k > F$ are necessary and sufficient conditions for $(t_I^*, t_E^*) = (D, A)$.

Parts *(g)* and *(h)*. Suppose $F > \hat{F}$. This implies that $\Pi_E(t_E, t_I) \le 0$. Thus, E chooses $t_E = Out$ at the second stage regardless what I chooses at the first stage. Therefore, there is no entry threat and the incumbent chooses t_I such that $\Pi_I^*(t_I, Out)$, for $t_I = \{D, A\}$, is the maximum payoff.

Part *(g)*. $t_I = D$ is the best response when $t_E = Out$ if $\Pi_I(D, Out) > \Pi_I(A, Out) \Longleftrightarrow \frac{1}{2} + \frac{2\alpha}{\beta(1-\lambda)} \frac{(\mu-1)k}{\beta(1-\lambda)} > \frac{V}{\beta(1-\lambda)}$.

Part *(h)*. $t_I = A$ is the best response when $t_E = Out$ if $\Pi_I(D, Out) < \Pi_I(A, Out) \Longleftrightarrow \frac{1}{2} + \frac{2\alpha}{\beta(1-\lambda)} \frac{(\mu-1)k}{\beta(1-\lambda)} < \frac{V}{\beta(1-\lambda)}$.

Part *(i)*. From Lemma 1 we have that entrant's best response to $t_I = D$ is $t_E = D$ if

$(\mu - 1)k > b_0$ and $\frac{\alpha}{2} - k > F$.

From Lemma 1 we have that entrant's best response to $t_I = A$ is $t_E = Out$ if

$\frac{\alpha}{2} - b_1 - k < F$ and $\frac{\alpha}{2} - \mu k < F$.

The condition such that the incumbent chooses $t_I = A$ is:

$(\mu - 1)k < \frac{V^2}{4\alpha} - \frac{\alpha}{2}$.

$\square$

Lemma 2.

Proof. The proof follows directly from the discussion in Subsection 1.4.1

$\square$

4.2   Consumer Surplus Chapter 1

The consumer surplus in each possible outcome is given by:

$$CS^{(D,Out)} = \lambda \int_0^{l_D}(V - p_I - \alpha(y - l_I))\, dy + (1-\lambda) \int_0^{l_N}(V - p_I - \alpha(y - l_I))\, dy - \beta(1 - \lambda).$$

$$CS^{ED(A,Out)} = \lambda \int_0^{l_D}(V - p_I - \alpha(y - l_I)) + (1 - \lambda) \int_0^{l_N}(V - p_I - \alpha(y - l_I))\, dy.$$

$$CS^{(D,D)} = \lambda \left[\int_0^{l_D} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_D}^1 (V - p_E - \alpha(l_E - y))\, dy \right] +$$
$$(1 - \lambda) \left[\int_0^{l_N} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_N}^1 (V - p_E - \alpha(l_E - y))\, dy \right] - \beta(1 - \lambda).$$

$$CS^{(A,A)} = \lambda \left[\int_0^{l_D} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_D}^1 (V - p_E - \alpha(l_E - y))\, dy \right] +$$
$$(1 - \lambda) \left[\int_0^{l_N} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_N}^1 (V - p_E - \alpha(l_E - y))\, dy \right].$$

$$CS^{(A,D)} = \lambda \left[\int_0^{l_D} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_D}^1 (V - p_E - \alpha(l_E - y))\, dy \right] +$$
$$(1 - \lambda) \left[\int_0^{l_N} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_N}^1 (V - p_E - \alpha(l_E - y))\, dy \right].$$

$$CS^{(D,A)} = \lambda \left[\int_0^{l_D} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_D}^1 (V - p_E - \alpha(l_E - y))\, dy \right] +$$
$$(1 - \lambda) \left[\int_0^{l_N} (V - p_I - \alpha(y - l_I))\, dy + \int_{l_N}^1 (V - p_E - \alpha(l_E - y))\, dy \right].$$

4.3 Proofs Chapter 2

Lemma 5.

Proof. Suppose that $u_i < u_i^*$. Then, the payoff of buying from firm i is $u_i - p_i < u_i^* - p_i$, and the expected payoff from visiting firm j and finding a better deal than at firm i is $\int_{u_i - p_i + p_j}^{\overline{u}} (u_j - p_j) g(u_j) du_j - s > \int_{u_i^* - p_i + p_j}^{\overline{u}} (u_j - p_j) g(u_j) du_j - s$. Therefore, the consumer is better off searching on firm j than buying from i inmediately.

Suppose that $u_i > u_i^*$. Then, the payoff of buying from firm i is $u_i - p_i > u_i^* - p_i$, and the expected payoff from visiting firm j and finding a better deal than at firm i is $\int_{u_i - p_i + p_j}^{\overline{u}} (u_j - p_j) g(u_j) du_j - s < \int_{u_i^* - p_i + p_j}^{\overline{u}} (u_j - p_j) g(u_j) du_j - s$. Therefore, the consumer would never search on firm j. $\qquad\square$

Lemma 6.

Proof. I need to show that the equilibrium price is a decreasing function of cost-reduction investment. Taking partial derivative from the equilibrium price:

$$\frac{\partial p_i^*(\gamma_i, \gamma_j)}{\partial \gamma_i} = -\frac{2}{3\gamma_i^2} < 0$$

for $\gamma_i \in (0, \infty)$. $\qquad\square$

Proposition 2.

Proof. The first order conditions with a support $[\underline{u}, \overline{u}] = [4, 5]$ are the following

$$k\gamma_i^2 = \frac{1}{18\gamma_i} + \frac{1}{9\gamma_i\gamma_j}$$

$$k\gamma_j^2 = \frac{1}{18\gamma_j} + \frac{1}{9\gamma_i\gamma_j}$$

Solving this system of two equations:

$$\gamma_i^* = \gamma_j^* = \gamma^* = Rootof\left(6k\gamma^3 - 1\right)$$

which has three possible solutions: $\gamma_1 \in \mathbb{R}$, and $\gamma_2, \gamma_3 \in \mathbb{C}$. The real solution is

$$\gamma_i^* = \gamma_j^* = \gamma^* = \frac{1}{6}\left(\frac{36}{k}\right)^{\frac{1}{3}} \tag{4.1}$$

Then, replacing (4.1) into the equilibrium prices (2.8):

$$p_i^*\left(\gamma_i^*, \gamma_j^*\right) = p_j^*\left(\gamma_j^*, \gamma_i^*\right) = p^* = \frac{1}{2} + 6\left(\frac{k}{36}\right)^{\frac{1}{3}} \tag{4.2}$$

Then, replacing (4.2) into the profit function:

$$\Pi_i^*\left(\gamma_i^*, \gamma_j^*\right) = \Pi_j^*\left(\gamma_j^*, \gamma_i^*\right) = \Pi^* = \frac{1}{4} - \left(\frac{k}{6}\right)^{\frac{1}{3}} \tag{4.3}$$

Now, it is necessary to impose a restriction in the domain of the profit function: k is such that $\Pi_i^*\left(\gamma_i^*, \gamma_j^*\right) \in \mathbb{R}_+$. Therefore, $k \in (0, \frac{3}{32}]$.

Finally, replacing (4.1) into the second order condition,

$$\frac{-18k + 46^{\frac{1}{3}}k^{\frac{1}{3}}}{3} > 0$$

for $k \in (0, \frac{729}{48})$. Therefore, the equilibrium satisfies the second order condition. $\square$

4.4 Equilibrium prices with prominence: solution 2

Solution 2:

$$p_i^*\left(\gamma_i, \gamma_j\right) = -\frac{1}{\gamma_i} - \frac{11 + 8s + (2-m)m + (1+m)A}{4(1+m+A)}$$

$$p_j^*\left(\gamma_j, \gamma_i\right) = \frac{1}{\gamma_j} - \frac{5 - 8s - (2-m)m - (1+m)A}{4(1+m+A)}$$

where $m = \frac{1}{\gamma_i} - \frac{1}{\gamma_j}$ and $A = \sqrt{9 - 6m + m^2 + 16s}$.

4.5 Equilibrium Prices with prominence: best response functions

In order to check that equilibrium prices are in the *right direction* I plot the best response function of each firm. For the prominent firm, I plot the response of firm i's equilibrium prices in terms of the R&D effort of the non-prominent firm (γ_j), assuming $\gamma_i = 1$. For the best response of firm j, fixed $\gamma_j = 1$ and plot the non-prominent equilibrium prices in terms of γ_i.

Notice that the equilibrium prices of both firms have the expected path. In Figure 4.1 (a) the prominent firm charges a lower price when the non-prominent firm invests more in R&D because the non-prominent firm behaves more aggressive. Figure 4.1 (b) shows a similar response of the non-prominent firm. The main difference is that the best response function of the prominent firm is more convex than the response function of the non-prominent firm, that is

$$\left.\frac{\partial p_i^*(\gamma_i, \gamma_j)}{\partial \gamma_j}\right|_{\gamma_i=1} > \left.\frac{\partial p_j^*(\gamma_j, \gamma_i)}{\partial \gamma_i}\right|_{\gamma_j=1}$$

4.6 Consumer Surplus Chapter 2

Random Search

The consumer surplus when consumers search randomly between firms is calculated as follows. The superscript indicates where consumers buy from and the subscript indicates the order of visits made by the consumers. For example, the subscript ij means that a consumer start visiting firm i first and, then, visits firm j.

Figure 4.1: Best response functions

(a) For $\gamma_i = 1$　　　　　　　　　(b) For $\gamma_j = 1$
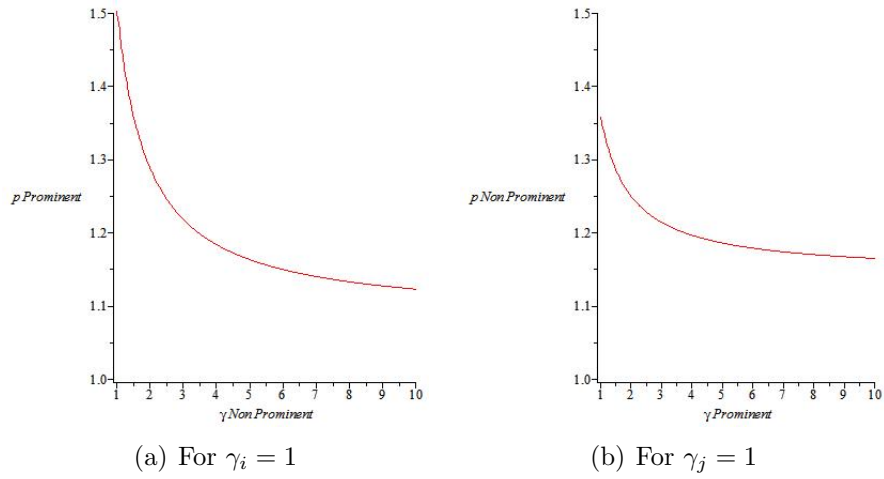
- Consumers who buy inmediately from firm i:

$$cs_i^i = \int_{u_i^*}^{\overline{u}} (u_i - p_i^* - s) \, du_i$$

- Consumers who started visiting firm i, visited firm j and go back to buy from firm i:

$$cs_{ij}^i = \int_{\underline{u}}^{u_i^*} \int_{\underline{u}}^{u_i - p_i^* + p_j^*} (u_i - p_i^* - 2s) \, du_j du_i$$

- Consumers who started visiting firm j, visited firm i and buy from it:

$$cs_{ji}^i = \int_{\underline{u}}^{u_j^*} \int_{u_j - p_j^* + p_i^*}^{\overline{u}} (u_i - p_i^* - 2s) \, du_i du_j$$

- Total consumer surplus:

$$cs = cs_i^i + cs_{ij}^i + cs_{ji}^i$$

Given that in equilibrium $p_i^* = p_j^* = p^*$, then $u_i^* = u_j^* = u^* = \overline{u} - \sqrt{2s}\sqrt{(\overline{u} - \underline{u})}$. Therefore:

- Consumers who buy immediately from firm i:

$$cs_i^i = \int_{u_i^*}^{\overline{u}} (u_i - p^* - s) \, du_i$$

- Consumers who started visiting firm i, visited firm j and go back to buy from firm i:

$$cs_{ij}^i = \int_{\underline{u}}^{u^*} \int_{\underline{u}}^{u_i} (u_i - p^* - 2s) \, du_j du_i$$

- Consumers who started visiting firm j, visited firm i and buy from it:

$$cs_{ji}^i = \int_{\underline{u}}^{u^*} \int_{u_j}^{\overline{u}} (u_i - p^* - 2s) \, du_i du_j$$

Prominence

The consumer surplus when all consumers start visiting the prominent firm first is calculated as follows.

- Consumers who buy immediately from the prominent firm:

$$CS_i^i = \int_{u_i^*}^{\overline{u}} (u_i - p_i^* - s) \, du_i$$

- Consumers who buy from the prominent firm after sampling the non-prominent firm:

$$CS_{ij}^i = \int_{\underline{u}}^{u_i^*} \int_{\underline{u}}^{u_i - p_i^* + p_j^*} (u_i - p_i^* - 2s) \, du_j du_i$$

- Consumers who buy from the non-prominent firm:

$$CS_{ij}^j = \int_{\underline{u}}^{u_i^*} \int_{u_j - p_j^* + p_i^*}^{\overline{u}} (u_j - p_j^* - 2s) \, du_i du_j$$

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Table 4.1: Consumer Surplus

k	Random				Prominence			
	Immed	Rival	Returning	Total	Immed	Rival	Returning	Total
0.00075	1.305	1.744	0.810	3.859	1.437	1.782	0.820	4.039
0.001	1.300	1.737	0.806	3.842	1.430	1.776	0.816	4.022
0.0025	1.279	1.708	0.790	3.777	1.405	1.748	0.803	3.956
0.005	1.259	1.679	0.775	3.713	1.300	1.687	0.776	3.763
0.010	1.233	1.642	0.757	3.632	1.243	1.642	0.755	3.640
0.025	1.189	1.580	0.724	3.493	1.227	1.579	0.721	3.527
0.050	1.146	1.517	0.692	3.354	1.239	1.518	0.686	3.443
0.075	1.115	1.474	0.669	3.258	1.252	1.471	0.660	3.383

Immed: consumer surplus from those consumers who buy immediately.
Rival: consumer surplus from those consumers who buy form the rival firm.
Returning: consumer surplus from those consumers who go back to the first visited firm.
Calculations have been done assuming $s = 0.05$.

- Total consumer surplus:

$$CS = CS_i^i + CS_{ij}^i + CS_{ij}^j$$

4.7 Proofs Chapter 3

Proposition 7.

Proof. If we take the partial derivatives at time t with respect to x^k with $k \geq t$ in equation (3.1) we obtain

$$\frac{\partial U^t}{\partial x^k} = -\sum_{i=k}^{\infty} \delta^{i-t} \left[\left(\frac{\gamma}{1+\gamma} \right)^{i-k+1} v' \left(\frac{1-\gamma x^i + \gamma(1-\gamma \bar{x}^{i-1})}{1+\gamma} \right) \right] + \delta^{k-t} (p_{1-x} - p_x)$$

where v' is the derivative of v with respect to D at time i. If we now compute the second partial derivatives we have

$$\frac{\partial^2 U^t}{\partial^2 x^k} = \sum_{i=k}^{\infty} \delta^{i-t} \left(\frac{\gamma}{1+\gamma} \right)^{i-k+2} v'' \left(\frac{1-\gamma x^t + \gamma(1-\gamma \bar{x}^{t-1})}{1+\gamma} \right).$$

As $v'' > 0$ implies $\frac{\partial^2 U^k}{\partial^2 x^k} > 0$ the optimal sequence $\{x^k\}_{k=t}^{\infty}$ has $x^k \in \{0,1\}$ for all $k = t, \ldots, \infty$. Moreover, if at the optimum $x^t = 1$ then it must be that

$$\sum_{i=t}^{\infty} \delta^{i-t} \left[v \left(\frac{1-\gamma+\gamma(1-\gamma \bar{x}^{i-1})}{1+\gamma} \right) - p_x \right] > \sum_{i=t}^{\infty} \delta^{i-t} \left[v \left(\frac{1+\gamma(1-\gamma \bar{x}^{i-1})}{1+\gamma} \right) - p_{1-x} \right].$$

Thus, since $v'' > 0$ and $x^t = 1$ implies $\bar{x}^t > \bar{x}^{t-1}$, we must have that

$$\sum_{i=t+1}^{\infty} \delta^{i-t} \left[v \left(\frac{1-\gamma+\gamma(1-\gamma \bar{x}^{i-1})}{1+\gamma} \right) - p_x \right] > \sum_{i=t+1}^{\infty} \delta^{i-t} \left[v \left(\frac{1+\gamma(1-\gamma \bar{x}^{i-1})}{1+\gamma} \right) - p_{1-x} \right].$$

Hence, if at the optimum $x^t = 1$ then at the optimum $x^{t+1} = 1$. Iterating on this reasoning we can conclude that if at the optimum $x^t = 1$ then it must be that at the optimum $x^k = 1$ for all $k = t, \ldots, \infty$. Using similar steps, it can be shown that if at the optimum $x^t = 0$ then the optimum has $x^k = 0$ for all $k = t, \ldots, \infty$. Therefore, the optimal sequence of unhealthy food consumption is such that $\{x^k\}_{k=t}^{\infty} = \{x\}_{k=t}^{\infty}$ with $x \in \{0,1\}$.

If $\bar{x}^{t-1} < \bar{x}$ then given that $v' > 0$ and $v'' > 0$ it is true that $v \left(\frac{1+\gamma(1-\gamma \bar{x}^{t-1})}{1+\gamma} \right) - p_{1-x} > v \left(\frac{1-\gamma+\gamma(1-\gamma \bar{x}^{t-1})}{1+\gamma} \right) - p_x$. This implies that the consumer derives maximum one period utility if she consumes $x = 0$ at time t. Furthermore, for all two sequences

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$\{x^k\}_0^T$ and $\{x^{k'}\}_0^T$ with $T > t$ that are different only in that $x^t = 0$ and $x^{t'} > 0$, we have that $v\left(D\left(\{x^k\}_0^T, 1 - x^T\right)\right) > v\left(D\left(\{x^{k'}\}_0^T, 1 - x^T\right)\right)$. Thus, if $\bar{x}^{t-1} < \bar{x}$ then the optimum has $x^k = 0$ for all $k \geq t$.

If $\bar{x}^{t-1} > \bar{x}$ then by similar arguments as those used above, the consumer derives maximum one period utility if she consumes $x = 1$ at time t. However, it is still true that for all two sequences $\{x^k\}_0^T$ and $\{x^{k'}\}_0^T$ with $T > t$ that are different only in that $x^t = 0$ and $x^{t'} > 0$, we have that $v\left(D\left(\{x^k\}_0^T, 1 - x^T\right)\right) > v\left(D\left(\{x^{k'}\}_0^T, 1 - x^T\right)\right)$. Hence, although the consumer derives more one period utility at time t if she consumes $x^t = 1$, if δ is high enough the gain in utility from consuming $x^t = 1$ instead of $x^t = 0$ does not offset the long term loss in utility. In this case we have that there exists a threshold value $\bar{\delta}$ such that if $\delta < \bar{\delta}$ then the optimal diet is $x^k = 0$ for all $k \geq t$ whilst if $\delta > \bar{\delta}$ then the optimal diet is $x^k = 1$ for all $k \geq t$. □

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