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„Differentiation in deposit-refund systems:
Can empty bottles create market power?"

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May every young woman have the same opportunities I did.

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Abstract

This thesis analyzes firms' incentives to create incompatibilities within deposit-refund systems. The analysis is conducted using a model of horizontal competition with heterogeneous products. First, firms choose to sell their products in standardized or differentiated packaging, then they enter a dynamic price competition consisting of two periods. Whenever at least one firm picks a differentiated bottle, both firms price at marginal costs in the first period of the price competition, and then gain monopoly power over their market share. In all three possible equilibria, all bottles get properly disposed but consumer welfare is lower compared to a system without deposits.

Kurzfassung

Die vorliegende Arbeit analysiert mögliche Anreize von Unternehmen Pfandsysteme inkompatibel zu gestalten. Die Analyse erfolgt mithilfe eines Models des horizontalen Wettbewerbs mit heterogenen Produkten. Im Model treffen Firmen zuerst die Entscheidung ihre Produkte in standardisierten oder eigenen Verpackungen zu verkaufen. Danach treten sie in einen dynamischen Preiswettbewerb, der in zwei Perioden abläuft. Entscheidet sich zumindest ein Unternehmen für eine herstellerspezifische Flasche, verlangen beide Firmen in der ersten Runde des Preiswettbewerbs nur ihre Grenzkosten. In der zweiten Runde können beide Monopolpreise verlangen. In allen drei möglichen Gleichgewichten werden alle Flaschen richtig entsorgt. Gleichzeitig ist die Konsumentenrente in den Gleichgewichten geringer im Vergleich zu keinem Pfandsystem.

1. Introduction

Debates regarding climate change have been present for decades. Recently, as the consequences of climate change are becoming more evident, the discussions regarding its severity are shifting towards possible ways to mitigate it, such as reduced meat consumption, slower extraction of natural resources, electromobility or sustainable housing concepts. Waste management, albeit likely less lucrative than electric cars or solar panels, is often overseen despite its potentially great impact.

Waste is problematic for mainly two reasons - the (often inappropriate) disposal leads to considerable greenhouse gas emissions, especially methane (Themelis & Ulloa, 2007), which is considered the second-largest contributor to climate change after carbon dioxide, according to the EU's factsheet on methane (European Commission, 2021b).

The perhaps less evident issue with waste is that the disposal of a good is often followed by the purchase of new items, using up further resources. The extraction of natural resources is recognized as a major driving force behind climate change (Oberle et al., 2019). Deposit-refund systems try to tackle both issues by taxing the waste creation during purchase and also subsidizing proper disposal (Bohm, 1981).

Consequently, deposit-refund systems appear to be a powerful tool in waste-management, both as a mitigating factor and as an incentive for proper disposal.

Yet, refundable bottles can often only be returned at shops that also sell them, potentially creating considerable costs for consumers. Interestingly, legislation appears not to be ignorant towards the impact of incompatibilities towards consumer surplus and the environment. The ban of mobile phone chargers using other non-standard connectors (European Commission, 2021a) indicates that authorities are aware of the potentially negative consequences of differentiation. However, the missing discussion on unification of refundable bottles (or other packaging) indicates that this issue has to date been overseen. This is particularly interesting as the usage of deposit-refund systems is steadily increasing. An Austrian grocery retailer[1] has for instance recently announced to expand their application of deposit-refund systems beyond beverages, the only caveat being that the retailer will not accept any type of packaging purchased at other shops.

Despite this, economic literature to date has not considered firms' incentives to create incompatibilities and their impact on the market structure. Most scholars interested in deposit-refund systems refer to Bohm (1981) as the initial literature in the field. Bohm formulated a basic theoretical framework for deposit-refund systems, focusing on effects on profits, consumer surplus and rates of returns as well as giving an extensive overview of potential policy applications. However, he solely focused on the firm's decision to switch to a deposit-refund system or the government installing mandatory, standardized systems, neglecting the option for differentiation within these systems.

This dimension of welfare consideration is also ignored by the rest of existing research on deposit-refund systems. Most of the literature evolves around the debate whether deposit-refund systems are a suitable policy for waste mitigation (Fenton and Hanley (1994), Fullerton (1996), Fullerton and Kinnaman (1995), Fullerton and Wolverton (2000), Fullerton and Wu (1998)) and the optimal size of the deposit (Mrozek (1996), Numata (2011), Millock (1994)).

No clear consensus exists regarding either of the questions. While deposit-refund systems do generate higher recycling rates compared to disposable options or other policies (Linderhof et al. (2019), Viscusi et al. (2013), Viscusi et al. (2014)), some scholars conclude they generate net social costs (Eggert and Weichenrieder (2004), Numata (2009), Porter (1978), Pearce and Turner (1992)) and that disposal costs (the degree of convenience of proper disposal) have a larger impact on recycling rates than the size of the deposit (Viscusi et al. (2012), Campbell et al. (2016), Bocken et al. (2022)).

Possible applications beyond beverage containers have also been explored. It appears

[1] see Heute, 07.03.2023

deposit-refund systems are also a good fit for toxic waste such as lead batteries (Gupt (2015), Sigman (1995)), lubricating oil (Belzer, 1989), medical waste (Grau, 1997) and even cars (Lee et al., 1992).

Regarding the size of the deposit, basic economic theory on externalities would suggest to have a deposit equivalent to the social cost (Stavins, 2003). However, if higher rates of return are desired, deposits higher than the social costs may be optimal (Millock, 1994).

While the impact of environmental policy on the market structure has been analyzed for instance by Xepapadeas et al. (1997), I was only able to find research regarding emission taxes and tradable emission permits, which do affect prices and the cost structure, but do not create opportunities to lock consumers in. There is, to my knowledge, no literature on the impact of deposit-refund systems on the market structure.

Interestingly, empirical evidence suggesting higher prices under deposit-refund systems can be found: Porter (1983) finds an increase in product prices after the introduction of a mandatory deposit-refund system in Michigan. He attributes this to increased production costs and does not consider differentiation as a possible explanation.

Moreover, deposit-refund systems have been analyzed in monopolistic and competitive settings (Bohm (1981), Kulshreshtha and Sarangi (2001)), but research to date perceives both settings as isolated cases, ignoring all settings in between, as well as the potential of deposit-refund systems to affect the market structure.

To summarize, deposit-refund systems appear to be a useful policy tool to tackle some of the current environmental challenges, such as illegal dumping of toxic waste or low recycling rate of materials like glass or plastic. The effects on profits and consumer surplus cannot be generalized. There are no papers to this date on the effects of incompatibilities within deposit-refund systems on the market structure.

Although the effects of differentiation has been ignored in the study of deposit-refund systems, they have been extensively analyzed in other frameworks: the arguably most famous result being Hotelling (1929), showing that firms have an incentive to maximally differentiate their products.

Moreover, the firms' incentive to create incompatibilities more often than would be socially optimal are described by Farrell and Klemperer (2007). Some applications involve printers (Klemperer, 2006), telecommunication (Zhu et al., 2011) or banking (Kim et al., 2003).

In these frameworks, firms increase consumers' switching costs, allowing them to raise prices in so-called ex-post markets. The particularity of deposit-refund systems lies in the relatively small and reoccurring switching cost at each purchase. Additionally, deposit-refund systems are specific as the consumers are presented with an outside option of simply not returning the bottle, which still allows them to consume the product. Nevertheless, deposits may still allow firms to lock their consumers in. Are empty bottles an opportunity for increased market power?

This thesis sheds light on the consequences of differentiation in deposit-refund systems, focusing on the beverage market with mandatory deposits on bottles. It does so by constructing a simple, 3-period model with two firms that can choose to sell their product in a standardized or differentiated bottle. We will see that picking a differentiated bottle allows to lock consumers in, and hence, both firms have an incentive to do so. Moreover, whenever at least one firm picks a differentiated bottle, both firms can charge monopoly prices in $\tau = 2$.

Section 2 sets up the model, that is solved in section 3. Section 4 conducts a welfare analysis, interprets the results and discusses possible extensions of the model. Section 5 concludes.

2. Model setup

2.1. Description of model

Two firms, A and B operate in a market with differentiated goods. The firms are located at the extremes of a Hotelling line (a unit interval of uniformly distributed consumers; see Chapter 5 of Belleflamme and Peitz (2010) for more). The firms set prices and sell their goods in refundable packaging.[1] They have the option to pick differentiated packaging (D), which can only be returned at the place of purchase. Alternatively, they can pick standardized packaging (S) that offers consumers flexibility and can be returned anywhere.

The unit mass of uniformly distributed consumers is myopic (i.e. $\delta = 0$, where δ denotes the time-discount factor). They all value the good at v, have unit demand, quadratic transportation costs (ta^2, where a denotes the distance between a consumer and a firm, and t is a positive parameter) and only care about prices.

The firms are forward-looking, but do not discount profits (i.e. $\delta = 1$). Furthermore, I assume no production cost, consumers' valuation (v) high enough for full market coverage and the size of the deposit (d) to be fixed. Hence, the only choice variable of firms is the price in each period. Additionally, I assume the deposit to be strictly positive and that it can only be redeemed in form of a coupon (i.e. it is not possible to go to one firm to return the bottle and then go purchase the product at another place).

The game has 3 periods, denoted τ. First, in

[1] I restrict the choice to standardized or differentiated refundable packaging, implying a mandatory deposit-refund system. For an analysis of the choice between disposable and refundable packaging, see Bohm (1981).

$\tau = 0$, firms simultaneously pick a type of packaging. Second, in

$\tau = 1$, firms observe the bottle choices, set prices ($p_{i,1} \geq 0$) and consumers make their first purchase at one of the firms. Finally, in

$\tau = 2$ firms observe the outcome of the previous period and set prices again. Then, consumers buy again and can return the bottle.

The game tree is depicted in appendix A.

2.1.1. Note on notation

Subgame SD denotes the subgame where firm A chose a standardized bottle and firm B did not. Subgame $SD1$ denotes the first period ($\tau = 1$) of subgame SD, and $SD2$ the second period ($\tau = 2$) of subgame SD.

$p^{\kappa}_{i,\tau}$ denotes the price of firm i in subgame κ, τ.

$p_i^{\kappa 2.\xi}$ denotes the price of firm i in case ξ of the second period of subgame κ.

$\lambda^{\phi}_{i,2}$ denotes the location of the consumer that purchased at firm i in $\tau = 1$ and is indifferent between staying at firm i or switching to the other, given that firm i chose a bottle of type $\phi \in \{S, D\}$.

2.1.2. Parametric restrictions

The following equilibrium analysis assumes $v > 3t$, $t > d > 0$ and $p \geq 0$. The first restriction ensures full market coverage. The second ensures that the deposits are relatively small, and the third condition restricts prices to realistic values.

2.1.3. Consumer choice in $\tau = 1$

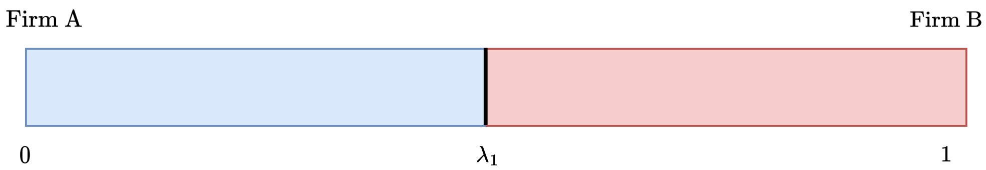
In $\tau = 1$ of all subgames, the consumer located at x buys at firm A iff

$$v - tx^2 - p_{A,1} \geq v - t(1-x)^2 - p_{B,1} \ . \tag{2.1}$$

Consequently, the consumer indifferent between buying from firm A and B in $\tau = 1$ of all subgames is at the same location as in a Hotelling game without refundable bottles, which is given by [2]

$$\lambda_1 = \frac{1}{2} - \frac{p_{A,1} - p_{B,1}}{2t} \ . \tag{2.2}$$

Figure 2.1.: Hotelling line in $\tau = 1$, with indifferent consumer at λ_1



2.1.4. Consumer choice in $\tau = 2$

The decision problem becomes more complex in $\tau = 2$, as it may be different for consumers located to the left of λ_1 and for those to the right of λ_1. For each fraction of these consumers, we can identify "loyals" (who will re-buy at the same firm) and "switchers" (who will purchase at the other firm).

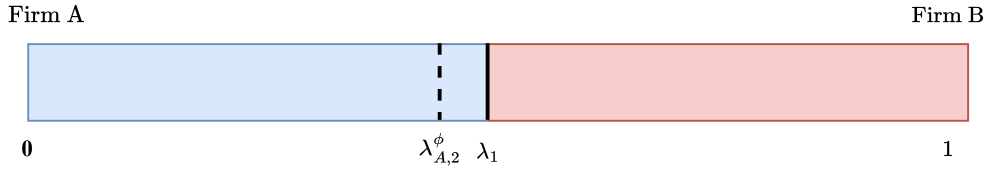
Identifying "loyals" and "switchers" for firm A

In $\tau = 2$, some consumers who have made their previous purchase at firm A may decide to switch to firm B. They are located between $\lambda^{\phi}_{A,2}$ and λ_1, as depicted in figure 3.2. Suppose firm A picked a standardized bottle. Then the consumer's decision problem is equivalent to (2.1) and hence, the consumer indifferent between re-buying at A and switching to B is located at

$$\lambda^S_{A,2} = \frac{1}{2} - \frac{p_{A,2} - p_{B,2}}{2t} \ . \tag{2.3}$$

[2] See Chapter 5 of Belleflamme and Peitz (2010).

Figure 2.2.: Hotelling line in $\tau = 2$, with potential switchers from A to B



Therefore, if $\lambda^{S}_{A,2} < \lambda_1$, the fraction $(\lambda_1 - \lambda^{S}_{A,2})$ will switch from A to B.

Now suppose firm A picked a differentiated bottle. Then all those who purchased at A in $\tau = 1$ will re-buy if

$$v - tx^2 - p_{A,2} + d \geq v - t(1-x)^2 - p_{B,2} \; . \tag{2.4}$$

Hence, the consumer indifferent between staying at A and switching to B is located at

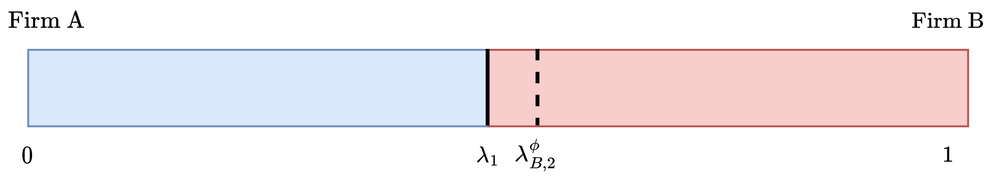
$$\lambda^{D}_{A,2} = \frac{1}{2} - \frac{p_{A,2} - p_{B,2} - d}{2t} \; . \tag{2.5}$$

Therefore, if $\lambda^{D}_{A,2} < \lambda_1$, the fraction $(\lambda_1 - \lambda^{D}_{A,2})$ will switch from A to B.

Identifying "loyals" and "switchers" for firm B

Similarly to firm A, some consumers of firm B may decide to switch to firm A in $\tau = 2$. They are located between λ_1 and $\lambda^{\phi}_{B,2}$, as depicted in figure 3.3. Suppose firm B picked a

Figure 2.3.: Hotelling line in $\tau = 2$, with potential switchers from B to A



standardized bottle. The consumer's decision problem is again equivalent to (2.1) and hence, the consumer indifferent between re-buying at B and switching to A is located at

$$\lambda_{B,2}^{S} = \frac{1}{2} - \frac{p_{A,2} - p_{B,2}}{2t} \ . \tag{2.6}$$

Therefore, if $\lambda_{B,2}^{S} > \lambda_1$, the fraction $(\lambda_{B,2}^{S} - \lambda_1)$ will switch from B to A.

Now suppose firm B picked a differentiated bottle. Then all those who purchased at B in $\tau = 1$ will re-buy if

$$v - tx^2 - p_{A,2} \leq v - t(1-x)^2 - p_{B,2} + d \ . \tag{2.7}$$

Hence, the consumer indifferent between staying at B and switching to A is located at

$$\lambda_{B,2}^{D} = \frac{1}{2} - \frac{p_{A,2} - p_{B,2} + d}{2t} \ . \tag{2.8}$$

Therefore, if $\lambda_{B,2}^{D} > \lambda_1$, the fraction $(\lambda_{B,2}^{D} - \lambda_1)$ will switch from B to A.

3. Solving the model

3.1. Demands

In $\tau = 1$, the demands are clearly given by

$$D^{\kappa}_{A,1} = \lambda_1,$$
$$D^{\kappa}_{B,1} = (1 - \lambda_1)\ .$$

The demands in $\tau = 2$ consist of loyals and switchers. They are given by

$$D^{\kappa}_{A,2} = \min\{\lambda_1, \lambda^{\phi}_{A,2}\} + \max\{\lambda^{\phi}_{B,2} - \lambda_1, 0\}, \tag{3.1}$$

where the first term are the loyals of firm A and the second term denotes the switchers of firm B, and

$$D^{\kappa}_{B,2} = 1 - \max\{\lambda_1, \lambda^{\phi}_{B,2}\} + \max\{\lambda_1 - \lambda^{\phi}_{A,2}, 0\}, \tag{3.2}$$

where the first term are the loyals of firm B and the second term denotes the switchers of firm A.

3.2. Subgame $SS2$

Using backward induction, we determine the equilibrium prices in subgame SS by first computing the equilibrium prices in $SS2$. Looking at (2.3) and (2.6), we see that there is no need to treat loyals and switchers separately, as all consumers face the same decision problem. The game again breaks down to a standard Hotelling game, leading to equilibrium prices and profits given by[1]

$$p_A^{SS2*} = p_B^{SS2*} = t, \tag{3.3}$$

$$\pi_A^{SS2*} = \pi_B^{SS2*} = \frac{t}{2} \ . \tag{3.4}$$

3.3. Subgame $SS1$

As both firms are forward looking, they take (3.3) as given in $\tau = 1$. However, as the equilibrium prices and profits in subgame $SS2$ are independent of the prices in subgame $SS1$, the firms again face a simple Hotelling problem in $\tau = 1$, leading to[2]

$$p_A^{SS1*} = p_B^{SS1*} = t, \tag{3.5}$$

$$\pi_A^{SS1*} = \pi_B^{SS1*} = \frac{t}{2} \ . \tag{3.6}$$

Hence, the overall profits of subgame SS are given by

$$\pi_A^{SS*} = \pi_B^{SS*} = t \ . \tag{3.7}$$

[1] see Chapter 5 of Belleflamme and Peitz (2010)

[2] see Chapter 5 of Belleflamme and Peitz (2010)

3.4. Subgame $SD2$

Using backward induction, we determine the equilibrium prices in subgame SD by first computing the equilibrium prices in $SD2$. Firm A's profits are given by

$$\begin{aligned}
\pi_A^{SD} &= D_{A,2}^{SD} p_{A,2}, \\
\pi_A^{SD} &= \left(\min\{\lambda_1, \lambda_{A,2}^S\} + \max\{\lambda_{B,2}^D - \lambda_1, 0\}\right) p_{A,2} \ .
\end{aligned}$$

Firm B's profits are given by

$$\begin{aligned}
\pi_B^{SD} &= D_{B,2}^{SD} p_{B,2}, \\
\pi_B^{SD} &= \left(1 - \max\{\lambda_1, \lambda_{B,2}^D\} + \max\{\lambda_1 - \lambda_{A,2}^S, 0\}\right) p_{A,2} \ .
\end{aligned}$$

We now need a case distinction to find the equilibrium prices and profits.

3.4.1. Case 1: $\lambda_1 \geq \lambda_{A,2}^S \ \wedge \ \lambda_1 \geq \lambda_{B,2}^D$

Whenever $\lambda_1 \geq \lambda_{A,2}^S \ \wedge \ \lambda_1 \geq \lambda_{B,2}^D$, firm A's profits are given by

$$\pi_A^{SD2.1} = \lambda_{A,2}^S p_{A,2} \ .$$

Plugging in (2.3) yields

$$\pi_A^{SD2.1} = \left(\frac{1}{2} - \frac{p_{A,2} - p_{B,2}}{2t}\right) p_{A,2} \ .$$

The first-order condition reads

$$\frac{\partial \pi_A^{SD2.1}}{\partial p_{A,2}} = \frac{1}{2} - \frac{2p_A^{SD2.1*} - p_{B,2}}{2t} \stackrel{!}{=} 0 \ .$$

Solving for $p_A^{SD2.1*}$, we obtain

$$p_A^{SD2.1*} = \frac{t + p_{B,2}}{2} \ . \tag{3.8}$$

Firm B's profits in this case are given by

$$\pi_B^{SD2.1} = \left((1-\lambda_1) + \left(\lambda_1 - \lambda_{A,2}^S\right)\right) p_{B,2} = \left(1 - \lambda_{A,2}^S\right) p_{B,2} \ .$$

Plugging in (2.3) yields

$$\pi_B^{SD2.1} = \left(\frac{1}{2} + \frac{p_{A,2} - p_{B,2}}{2t}\right) p_{B,2} \ .$$

The first-order condition reads

$$\frac{\partial \pi_B^{SD2.1}}{\partial p_{B,2}} = \frac{1}{2} + \frac{p_{A,2} - 2p_B^{SD2.1*}}{2t} \overset{!}{=} 0 \ .$$

Solving for $p_B^{SD2.1*}$, we obtain

$$p_B^{SD2.1*} = \frac{t + p_{A,2}}{2} \ . \tag{3.9}$$

The price equilibrium lies at the intersection of (3.8) and (3.9). It is given by

$$p_A^{SD2.1*} = p_B^{SD2.1*} = t \ . \tag{3.10}$$

Plugging (3.10) into (2.3) and (2.8) leads to

$$\lambda_{A,2}^{S.1*} = \frac{1}{2} - \frac{t-t}{2t} = \frac{1}{2}, \tag{3.11}$$

$$\lambda_{B,2}^{D.1*} = \frac{1}{2} - \frac{t-t-d}{2t} = \frac{1}{2} - \frac{d}{2t} \ . \tag{3.12}$$

Therefore, the equilibrium prices of this case are feasible iff

$$\lambda_1 \geq \frac{1}{2}, \tag{3.13}$$

which holds iff

$$p_{A,1} \leq p_{B,1} \ . \tag{3.14}$$

The equilibrium profits in case 1 of subgame $SD2$ are given by

$$\pi_A^{SD2.1*} = \lambda_{A,2}^{S*} p_A^{SD2.1*} = \frac{t}{2}, \tag{3.15}$$

$$\pi_B^{SD2.1*} = \left(1 - \lambda_{A,2}^{S*}\right) p_B^{SD2.1*} = \frac{t}{2} \ . \tag{3.16}$$

To give some intuition, think about $\lambda_1 = 1$, meaning all consumers bought at A in $\tau = 1$. Then all consumers' decision problem is given by (2.1) and the game becomes equivalent to subgame SS.

3.4.2. Case 2: $\lambda_1 \leq \lambda_{A,2}^S \ \wedge \ \lambda_1 \leq \lambda_{B,2}^D$

Whenever $\lambda_1 \leq \lambda_{A,2}^S \ \wedge \ \lambda_1 \leq \lambda_{B,2}^D$, firm A's profits are given by

$$\pi_A^{SD2.2} = \lambda_1 p_{A,2} + \left(\lambda_{B,2}^D - \lambda_1\right) p_{A,2} = \lambda_{B,2}^D p_{A,2} \ .$$

Plugging in (2.8) gives

$$\pi_A^{SD2.2} = \left(\frac{1}{2} - \frac{p_{A,2} - p_{B,2} + d}{2t}\right) p_{A,2} \ .$$

The first-order condition reads

$$\frac{\partial \pi_A^{SD2.2}}{\partial p_{A,2}} = \frac{1}{2} - \frac{2p_A^{SD2.2*} - p_{B,2} + d}{2t} \stackrel{!}{=} 0 \ .$$

Solving for $p_A^{SD2.2*}$, we obtain

$$p_A^{SD2.2*} = \frac{t + p_{B,2} - d}{2} \ . \tag{3.17}$$

Firm B's profits in this case are given by

$$\pi_B^{SD2.2} = \left(1 - \lambda_{B,2}^D\right) p_{B,2} = \left(\frac{1}{2} + \frac{p_{A,2} - p_{B,2} + d}{2t}\right) p_{B,2} \, .$$

The first-order condition reads

$$\frac{\partial \pi_B^{SD2.2}}{\partial p_{B,2}} = \frac{1}{2} + \frac{p_{A,2} - 2p_B^{SD2.2*} + d}{2t} \stackrel{!}{=} 0 \, .$$

Solving for $p_B^{SD2.2*}$, we obtain

$$p_B^{SD2.2*} = \frac{t + p_{A,2} + d}{2} \, . \tag{3.18}$$

The price equilibrium lies at the intersection of (3.17) and (3.18). It is given by

$$p_A^{SD2.2*} = t - \frac{d}{3}, \tag{3.19}$$

$$p_B^{SD2.2*} = t + \frac{d}{3} \, . \tag{3.20}$$

Plugging (3.19) and (3.20) into (2.3) and (2.8) leads to

$$\lambda_{A,2}^{S.2*} = \frac{1}{2} - \frac{t - \frac{d}{3} - t - \frac{d}{3}}{2t} = \frac{1}{2} + \frac{d}{3t}, \tag{3.21}$$

$$\lambda_{B,2}^{D.2*} = \frac{1}{2} - \frac{t - \frac{d}{3} - t - \frac{d}{3} + d}{2t} = \frac{1}{2} - \frac{d}{6t} \, . \tag{3.22}$$

Therefore, the equilibrium prices of this case are feasible iff

$$\lambda_1 \leq \frac{1}{2} - \frac{d}{6t}, \tag{3.23}$$

which holds iff

$$p_{B,1} \leq p_{A,1} - \frac{d}{3} \, . \tag{3.24}$$

The equilibrium profits in case 2 of subgame $SD2$ are given by

$$\pi_A^{SD2.2*} = \lambda_{B,2}^{D*} p_A^{SD2.2*} = \frac{t}{2} - \frac{d}{3} + \frac{d^2}{18t}, \tag{3.25}$$

$$\pi_B^{SD2.2*} = \left(1 - \lambda_{B,2}^{D*}\right) p_B^{SD2.2*} = \frac{t}{2} + \frac{d}{3} + \frac{d^2}{18t} \ . \tag{3.26}$$

To give some intuition, think about $\lambda_1 = 0$, meaning all consumers bought at firm B in $\tau = 1$. Then the decision problem of all consumers is given by (2.7).

3.4.3. Case 3: $\lambda_{B,2}^D \leq \lambda_1 \leq \lambda_{A,2}^S$

Whenever $\lambda_{B,2}^D \leq \lambda_1 \leq \lambda_{A,2}^S$, firm A's profits are given by

$$\pi_A^{SD2.3} = \lambda_1 p_{A,2} \ .$$

Plugging in (2.2) gives

$$\pi_A^{SD2.3} = \left(\frac{1}{2} - \frac{p_{A,1} - p_{B,1}}{2t}\right) p_{A,2} \ .$$

The first-order condition reads

$$\frac{\partial \pi_A^{SD2.3}}{\partial p_{A,2}} = \frac{1}{2} - \frac{p_{A,1} - p_{B,1}}{2t} \stackrel{!}{=} 0,$$

which is independent of $p_{A,2}$. As the profits are increasing in $p_{A,2}$, firm A will charge

$$p_A^{SD2.3*} = \infty \ . \tag{3.27}$$

Firm B's profits are given by

$$\pi_B^{SD2.3} = (1 - \lambda_1)\, p_{B,2} \ .$$

Plugging in (2.2) gives

$$\pi_B^{SD2.3} = \left(\frac{1}{2} + \frac{p_{A,1} - p_{B,1}}{2t}\right) p_{B,2} \ .$$

The first-order condition reads

$$\frac{\partial \pi_B^{SD2.3}}{\partial p_{B,2}} = \frac{1}{2} + \frac{p_{A,1} - p_{B,1}}{2t} \stackrel{!}{=} 0,$$

which is independent of $p_{B,2}$. As the profits are increasing in $p_{B,2}$, firm B will charge

$$p_B^{SD2.3*} = \infty \ . \tag{3.28}$$

Although (3.27) and (3.28) do not give us a price equilibrium, they suggest monopolization. This case is analyzed further in section 3.4.5.

3.4.4. Case 4: $\lambda_{A,2}^S \leq \lambda_1 \leq \lambda_{B,2}^D$

We can see by plugging in (2.2), (2.3) and (2.8) that

$$\frac{1}{2} - \frac{p_{A,2} - p_{B,2}}{2t} \leq \frac{1}{2} - \frac{p_{A,1} - p_{A,1}}{2t} \leq \frac{1}{2} - \frac{p_{A,2} - p_{B,2} + d}{2t},$$

which can only be satisfied if $p_{A,1} - p_{B,1} = p_{A,2} - p_{B,2}$ and $d = 0$, which violates $d > 0$. Hence, this case can never occur.

3.4.5. Equilibrium in subgame $SD2$

We have seen that the firms' best-responses depend on λ_1. For λ_1 sufficiently low as given by (3.23), the price equilibrium is given by (3.19) and (3.20). For λ_1 sufficiently big as given by (3.13), the price equilibrium is given by (3.10). As for $\frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2}$, the equilibrium is still unclear from our previous analysis. Recall that (3.27) and (3.28) hint to monopolization.

Consider $p_{A,1} - p_{B,1} = 0$ as an illustrative example. Then $\lambda_1 = \frac{1}{2}$, and all consumers to the left of λ_1 re-buy at A iff (2.1) holds whereas all consumers to the right of λ_1 re-buy iff (2.7) holds. This means that the last consumer who bought at firm A in $\tau = 1$, located at $\frac{1}{2}$ will buy at A again iff $p_{A,2} \leq p_{B,2}$ and that the last consumer who bought at firm B in $\tau = 1$, located at $\frac{1}{2}$ will buy at A again iff $p_{B,2} \leq p_{A,2} + d$. This supports our guess that for $\frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2}$, firms can act as monopolists in $\tau = 2$. Let us assume for now that they do so, in equilibrium, and then check whether they want to deviate to competition.

Given that we have restricted the consumers' valuation to be relatively high, let us assume both monopolists want to serve their full market share and check later. If both firms want to serve their whole market share, their optimal price is such that the consumer located furthest away becomes indifferent between buying and not buying. The consumer closest to λ_1 who bought at firm A becomes indifferent once

$$v - t\,(\lambda_1)^2 - p_A^{SD2.3^{cand}} - d = -d\,. \tag{3.29}$$

The consumer closest to λ_1 who bought at firm B stops buying once

$$v - t\,(1-\lambda_1)^2 - p_B^{SD2.3^{cand}} - d = -d\,. \tag{3.30}$$

Solving for $p_A^{SD2.3^{cand}}$ and $p_B^{SD2.3^{cand}}$, we obtain

$$p_A^{SD2.3^{cand}} = v - t\,(\lambda_1)^2\,, \tag{3.31}$$

$$p_B^{SD2.3^{cand}} = v - t\,(1-\lambda_1)^2\ . \tag{3.32}$$

Note that by charging (3.31) and (3.32), both firms serve their whole respective markets and hence, lowering their prices would mean entering a price competition. We will check for this deviation later. First, let us check whether the firms want to raise their prices. If firm A prices according to (3.31), its profits are given by

$$\pi_A^{SD2.3^{cand}} = v\lambda_1 - t\,(\lambda_1)^3\ . \tag{3.33}$$

If the firm were to charge a higher price, its profits would be

$$\pi_A^{SD2.3^{dev}} = (\lambda_1 - \varepsilon)\left(v - t(\lambda_1)^2 - \varepsilon\right),$$
$$\pi_A^{SD2.3^{dev}} = \lambda_1 v - t(\lambda_1)^3 + \varepsilon(\lambda_1(t\lambda_1 - 1) + \varepsilon - v)$$

Note that deviation can only be profitable if the last expression is positive. Moreover, note that the expression is increasing in λ_1 and decreasing in v. Setting $\lambda_1 = 1$ and $v = 3t$ leads to deviation profits given by

$$\pi_A^{SD2.3^{dev}} = \lambda_1 v - t(\lambda_1)^3 + \varepsilon(\varepsilon - 2t - 1),$$

which is smaller than (3.33) for $t > \varepsilon > 0$. Hence, firm A does not want to deviate to a higher price and, by symmetry, neither does firm B. Now, let us confirm that (3.31) and (3.32) are interior solutions of case 3. Plugging them into (2.3) and (2.8) leads to

$$\lambda_{A,2}^{S.3^{cand}} = \frac{1}{2} - \frac{v - t(\lambda_1)^2 - v + t(1-\lambda_1)^2}{2t} = \lambda_1, \tag{3.34}$$
$$\lambda_{B,2}^{D.3^{cand}} = \frac{1}{2} - \frac{v - t(\lambda_1)^2 - v + t(1-\lambda_1)^2 + d}{2t} = \lambda_1 - d, \tag{3.35}$$

which satisfies the conditions for case 3. Finally, we need to check whether one of the firms has an incentive to enter a price competition for $\frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2}$. Firm A's lowest monopoly profits occur when $\lambda_1 = \frac{1}{2} - \frac{d}{6t}$. They are given by

$$\pi_A^{SD2.3^{cand}} = \frac{v}{2} - \frac{t}{8} - \frac{dv}{6t} + \frac{d}{8} - \frac{d^2}{24t} + \frac{d^3}{216t^2}. \tag{3.36}$$

Firm A can deviate to case 2 by pricing according to (3.17). This will lead to

$$p_A^{SD2.3^{dev}} = \frac{t + p_B^{SD2.3^{cand}} - d}{2}.$$

Plugging in (3.32) and $\lambda_1 = \frac{1}{2} - \frac{d}{6t}$ gives

$$p_A^{SD2.3^{dev}} = \frac{t + v - \frac{t}{4} - \frac{d}{6} - \frac{d^2}{36t} - d}{2} = \frac{v}{2} - \frac{3t}{8} - \frac{7d}{12} - \frac{d^2}{72t}. \tag{3.37}$$

The corresponding profits are given by

$$\pi_A^{SD2.3^{dev}} = \left(\frac{1}{2} - \frac{d}{6t}\right)\left(\frac{v}{2} - \frac{3t}{8} - \frac{7d}{12} - \frac{d^2}{72t}\right),$$
$$\pi_A^{SD2.3^{dev}} = \frac{v}{4} - \frac{3t}{16} - \frac{dv}{12t} - \frac{11d}{24} + \frac{13d^2}{144t} + \frac{d^3}{432t^2}, \tag{3.38}$$

which is smaller than (3.36) for $v > 3t$ and $t > d > 0$. Hence, firm A does not have an incentive to enter price competition. Firm B's lowest monopoly profits are at $\lambda_1 = \frac{1}{2}$. They are given by

$$\pi_B^{SD2.3^{cand}} = \frac{v}{2} - \frac{t}{8}\ . \tag{3.39}$$

Firm B can deviate to case 1 by pricing according to (3.9). This will lead to

$$p_B^{SD2.3^{dev}} = \frac{t + p_A^{SD2.3^{cand}}}{2}\ .$$

Plugging in (3.31) and $\lambda_1 = \frac{1}{2}$ gives

$$p_B^{SD2.3^{dev}} = \frac{t + v - \frac{t}{4}}{2} = \frac{v}{2} + \frac{3t}{8}\ . \tag{3.40}$$

The corresponding profits are given by

$$\pi_B^{SD2.3^{dev}} = \frac{1}{2}\left(\frac{v}{2} + \frac{3t}{8}\right) = \frac{v}{4} + \frac{3t}{16}, \tag{3.41}$$

which is smaller than (3.39) for $v > 3t$ and $t > d > 0$. Hence, firm B does not have an incentive to enter price competition, either. Consequently, for $\frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2}$, the equilibrium prices are given by

$$p_A^{SD2.3*} = v - t\left(\lambda_1\right)^2, \tag{3.42}$$
$$p_B^{SD2.3*} = v - t\left(1 - \lambda_1\right)^2\ . \tag{3.43}$$

To summarize, firms' profits in subgame $SD2$ are given by

$$\pi_A^{SD2*} = \begin{cases} \frac{t}{2} - \frac{d}{3} + \frac{d^2}{18t}, & \text{if } 0 \leq \lambda_1 < \frac{1}{2} - \frac{d}{6t} \\ \lambda_1 v - t\left(\lambda_1\right)^3, & \text{if } \frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2} \\ \frac{t}{2}, & \text{if } 1 \geq \lambda_1 > \frac{1}{2}, \end{cases} \tag{3.44}$$

$$\pi_B^{SD2*} = \begin{cases} \frac{t}{2} + \frac{d}{3} + \frac{d^2}{18t}, & \text{if } 0 \leq \lambda_1 < \frac{1}{2} - \frac{d}{6t} \\ \left(1-\lambda_1\right) v - t\left(1-\lambda_1\right)^3, & \text{if } \frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2} \\ \frac{t}{2}, & \text{if } 1 \geq \lambda_1 > \frac{1}{2}. \end{cases} \tag{3.45}$$

3.5. Subgame $SD1$

We have seen in the analysis of subgame $SD2$ that firm A's profits are maximized at $\lambda_1 = \frac{1}{2}$ whereas firm B's profits reach their maximum at $\lambda_1 = \frac{1}{2} - \frac{d}{6t}$. Therefore, in $\tau = 1$, firm B wants to undercut firm A by exactly $\frac{d}{3}$, whereas firm A always wants to match firm B's price. This can be expressed as

$$p_A^{SD1*} = p_{B,1}, \tag{3.46}$$

$$p_B^{SD1*} = p_{A,1} - \frac{d}{3}. \tag{3.47}$$

The firms will hence continue to undercut each other until they are not able to do so, anymore. This occurs once both charge 0. Then $\lambda_1 = \frac{1}{2}$ and both firms get $\frac{v}{2} - \frac{t}{8}$ in $\tau = 2$. Firm B has no incentive to deviate to a higher price in $\tau = 1$ as this would lead to $\lambda_1 < \frac{1}{2}$ and hence case 1. Firm A does not want to deviate to a higher price as it would get

$$\pi_A^{SD^{dev}} = \left(\frac{1}{2} - \frac{\varepsilon}{2t}\right)\varepsilon + \left(\frac{1}{2} - \frac{\varepsilon}{2t}\right)v - t\left(\frac{1}{2} - \frac{\varepsilon}{2t}\right)^3,$$

$$\pi_A^{SD^{dev}} = \frac{v}{2} - \frac{t}{8} - \frac{v\varepsilon}{2t} + \frac{7\varepsilon}{8} - \frac{7\varepsilon^2}{8t} + \frac{7\varepsilon^3}{8t^2},$$

which is smaller than $\frac{v}{2} - \frac{t}{8}$ for $v > 3t$ and $t > \varepsilon > 0$. Hence, neither firm has an incentive to deviate from charging marginal costs in $\tau = 1$.

3.6. Overall equilibrium in subgame SD

In the first period, the firms are essentially competing for market shares. The fierce price competition leads to

$$p_A^{SD1*} = p_B^{SD1*} = 0 \ . \tag{3.48}$$

In the second period, the game becomes equivalent to having two monopolies, leading to

$$p_A^{SD2*} = p_B^{SD2*} = v - \frac{t}{4} \ . \tag{3.49}$$

Overall equilibrium profits are given by

$$\pi_A^{SD*} = \pi_B^{SD*} = \frac{v}{2} - \frac{t}{8} \ . \tag{3.50}$$

3.7. Subgame DS

This subgame is equivalent to SD but with reversed roles. The equilibrium is given by

$$p_A^{DS1*} = p_B^{DS1*} = 0, \tag{3.51}$$

$$p_A^{DS2*} = p_B^{DS2*} = v - \frac{t}{4}, \tag{3.52}$$

and equilibrium profits are

$$\pi_A^{DS*} = \pi_B^{DS*} = \frac{v}{2} - \frac{t}{8} \ . \tag{3.53}$$

3.8. Subgame $DD2$

Unlike before, both firms now have the possibility to lock their consumers in. Using backward induction, we determine the equilibrium prices in subgame DD by first computing the equilibrium prices in $DD2$. Firm A's profits are given by

$$\pi_A^{DD} = D_{A,2}^{DD} p_{A,2},$$
$$\pi_A^{DD} = \left(\min\{\lambda_1, \lambda_{A,2}^D\} + \max\{\lambda_{B,2}^D - \lambda_1, 0\}\right) p_{A,2} \, .$$

Firm B's profits are given by

$$\pi_B^{DD} = D_{B,2}^{DD} p_{B,2},$$
$$\pi_B^{DD} = \left(1 - \max\{\lambda_1, \lambda_{B,2}^D\} + \max\{\lambda_1 - \lambda_{A,2}^D, 0\}\right) p_{A,2} \, .$$

We now need a case distinction to find the equilibrium prices and profits.

3.8.1. Case 1: $\lambda_1 \geq \lambda_{A,2}^D \ \wedge \ \lambda_1 \geq \lambda_{B,2}^D$

Whenever $\lambda_1 \geq \lambda_{A,2}^D \ \wedge \ \lambda_1 \geq \lambda_{B,2}^D$, firm A's profits are given by

$$\pi_A^{DD2.1} = \lambda_{A,2}^D p_{A,2} \, .$$

Firm B's profits in this case are given by

$$\pi_B^{DD2.1} = \left(1 - \lambda_{A,2}^D\right) p_{B,2} \, .$$

Note that the profits are now equivalent to those in case 2 of subgame $SD2$ with reversed roles for A and B. Consequently, we get

$$p_A^{DD2.1*} = t + \frac{d}{3}, \tag{3.54}$$
$$p_B^{DD2.1*} = t - \frac{d}{3} \tag{3.55}$$

Plugging (3.54) and (3.55) into (2.5) and (2.8) leads to

$$\lambda_{A,2}^{D*} = \frac{1}{2} - \frac{p_{A,2}^{*} - p_{B,2}^{*} - d}{2t} = \frac{1}{2} - \frac{t + \frac{d}{3} - t + \frac{d}{3} - d}{2t} = \frac{1}{2} + \frac{d}{6t}, \tag{3.56}$$

$$\lambda_{B,2}^{D*} = \frac{1}{2} - \frac{p_{A,2}^{*} - p_{B,2}^{*} + d}{2t} = \frac{1}{2} - \frac{t + \frac{d}{3} - t + \frac{d}{3} - d}{2t} = \frac{1}{2} - \frac{5d}{6t} \tag{3.57}$$

Therefore, the equilibrium prices of this subgame are feasible iff

$$\lambda_1 \geq \frac{1}{2} + \frac{d}{6t}, \tag{3.58}$$

which holds iff

$$p_{A,1} \leq p_{B,1} - \frac{d}{3} \; . \tag{3.59}$$

By symmetry to case 2 of subgame $SD2$, the equilibrium profits in case 1 of subgame $DD2$ are given by

$$\pi_A^{DD2.1*} = \frac{t}{2} + \frac{d}{3} + \frac{d^2}{18t}, \tag{3.60}$$

$$\pi_B^{DD2.1*} = \frac{t}{2} - \frac{d}{3} + \frac{d^2}{18t} \; . \tag{3.61}$$

3.8.2. Case 2: $\lambda_1 \leq \lambda_{A,2}^D \ \wedge \ \lambda_1 \leq \lambda_{B,2}^D$

Whenever $\lambda_1 \leq \lambda_{A,2}^D \ \wedge \ \lambda_1 \leq \lambda_{B,2}^D$, firm A's profits are given by

$$\pi_A^{DD2.2} = \lambda_1 p_{A,2} + \left(\lambda_{B,2}^D - \lambda_1\right) p_{A,2} = \lambda_{B,2}^D p_{A,2} \; .$$

Firm B's profits are given by

$$\pi_B^{DD2.2} = \left(1 - \lambda_{B,2}^D\right) p_{B,2} \; .$$

Note that the profits are now equivalent to those in case 2 of subgame $SD2$. The equilibrium prices are hence given by (3.19) and (3.20). The equilibrium profits are given by (3.25) and (3.26). This case occurs whenever (3.24) holds.

3.8.3. Case 3: $\lambda^D_{B,2} \leq \lambda_1 \leq \lambda^D_{A,2}$

Whenever $\lambda^D_{B,2} \leq \lambda_1 \leq \lambda^D_{A,2}$, firm A's profits are given by

$$\pi_A^{DD2.3} = \lambda_1 p_{A,2} \ .$$

Firm B's profits are given by

$$\pi_B^{DD2.3} = (1 - \lambda_1)\, p_{B,2} \ .$$

Note that this is equivalent to case 3 of subgame $SD2$ and hence, we again get strictly positive first-order conditions. This case is analyzed further in section 3.8.5.

3.8.4. Case 4: $\lambda^D_{A,2} \leq \lambda_1 \leq \lambda^D_{B,2}$

We can see by plugging in (2.2), (2.5) and (2.8) that

$$\frac{1}{2} - \frac{p_{A,2} - p_{B,2} - d}{2t} \leq \frac{1}{2} - \frac{p_{A,1} - p_{A,1}}{2t} \leq \frac{1}{2} - \frac{p_{A,2} - p_{B,2} + d}{2t}$$

can only be satisfied if $p_{A,1} - p_{B,1} = p_{A,2} - p_{B,2}$ and $d = 0$, which violates $d > 0$. Hence, this case can never occur.

3.8.5. Equilibrium in subgame $DD2$

As in subgame $SD2$, the firms' best-responses depend on λ_1. For λ_1 sufficiently low as given by (3.23), the price equilibrium is given by (3.19) and (3.20). For λ_1 sufficiently large as given by (3.58), the price equilibrium is given by (3.54) and (3.55). By the same arguments as in section 4.4.5, the prices charged in $DD2$ whenever $\frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2} + \frac{d}{6t}$ are given by (3.42), (3.43). To summarize, the firms' profits in subgame $DD2$ are given by

$$\pi_A^{DD2*} = \begin{cases} \frac{t}{2} - \frac{d}{3} + \frac{d^2}{18t}, & \text{if } 0 \leq \lambda_1 < \frac{1}{2} - \frac{d}{6t} \\ \lambda_1 v - t(\lambda_1)^3, & \text{if } \frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2} + \frac{d}{6t} \\ \frac{t}{2} + \frac{d}{3} + \frac{d^2}{18t} & \text{if } 1 \geq \lambda_1 > \frac{1}{2} + \frac{d}{6t}, \end{cases} \tag{3.62}$$

$$\pi_B^{DD2*} = \begin{cases} \frac{t}{2} + \frac{d}{3} + \frac{d^2}{18t}, & \text{if } 0 \leq \lambda_1 < \frac{1}{2} - \frac{d}{6t} \\ (1-\lambda_1) v - t(1-\lambda_1)^3, & \text{if } \frac{1}{2} - \frac{d}{6t} \leq \lambda_1 \leq \frac{1}{2} + \frac{d}{6t} \\ \frac{t}{2} - \frac{d}{3} + \frac{d^2}{18t} & \text{if } 1 \geq \lambda_1 > \frac{1}{2} + \frac{d}{6t}\ . \end{cases} \tag{3.63}$$

3.9. Subgame $DD1$

Analogously to our analysis in subgame SD, we can see that firm A's profits are maximized at $\frac{1}{2} + \frac{d}{6t}$ whereas firm B's profits reach their maximum at $\frac{1}{2} - \frac{d}{6t}$. Consequently, each firm wants to undercut the other by $\frac{d}{3}$ and both again charge 0 in equilibrium.

3.10. Overall equilibrium in subgame DD

As in the asymmetric subgames, the firms are essentially competing for market shares in $\tau = 1$, leading to

$$p_A^{DD1*} = p_B^{DD1*} = 0\ . \tag{3.64}$$

In the second period, the game becomes equivalent to having two monopolies, leading to

$$p_A^{DD2*} = p_B^{DD2*} = v - \frac{t}{4}\ . \tag{3.65}$$

Overall equilibrium profits are given by

$$\pi_A^{DD*} = \pi_B^{DD*} = \frac{v}{2} - \frac{t}{8}\ . \tag{3.66}$$

3.11. Bottle choice: finding the SPNE

We have seen in section 3.3 that whenever both firms choose standardized packaging, installing a deposit-refund system leads to the same prices as a system with no deposits. Hence, if no firm creates incompatibilities, deposit-refund systems create no market power.

However, the analysis conducted in sections 3.4 to 3.10 suggests that once at least one firm chooses a non-standardized packaging, both firms act as local monopolists in $\tau = 2$. Therefore, they price at marginal costs in $\tau = 1$ to maximize their market shares.

To summarize the equilibrium payoffs of the separate subgames, they are represented in the following matrix. We can see that for $v > 3t$, the game has 3 subgame perfect

		Firm B	
		S	D
Firm A	S	$t, \quad t$	$\underline{\frac{v}{2} - \frac{t}{8}}, \quad \underline{\frac{v}{2} - \frac{t}{8}}$
	D	$\underline{\frac{v}{2} - \frac{t}{8}}, \quad \underline{\frac{v}{2} - \frac{t}{8}}$	$\underline{\frac{v}{2} - \frac{t}{8}}, \quad \underline{\frac{v}{2} - \frac{t}{8}}$

equilibria, given by (S, D), (D, S), and (D, D). For lower values of v, the monopoly profits in $\tau = 2$ may not be high enough to offset the loss that firms incur in $\tau = 1$, and hence, the firms may prefer to stick to a standardized system.

4. Interpreting results

4.1. Welfare analysis

Note that in all subgame equilibria, the market gets split equally. Therefore, it suffices to compare the consumer surplus generated by the consumer located the furthest away from both firms. If both firms pick a standardized bottle, the consumer surplus of the consumer located at $\frac{1}{2}$ is given by

$$2\left(v - t - \frac{t}{4}\right) = 2v - \frac{5t}{2} \ . \tag{4.1}$$

If at least one firm picks a standardized bottle, the consumer surplus of the consumer located at $\frac{1}{2}$ is given by

$$v - \frac{t}{4} + 0 = v - \frac{t}{4} \ . \tag{4.2}$$

Note that for $v > 3t$, (4.1) is always greater than (4.2). Consequently, overall consumer surplus decreases whenever at least one firm picks a non-standardized bottle. Recall that subgame SS is equivalent to a game without deposits. Therefore, the introduction of a mandatory deposit-refund system leads to lower consumer surplus if firms do not have to stick to a standardized system.

As for the rate of return of the bottles, we can see that all bottles will get properly disposed, as the market shares in $\tau = 1$ and $\tau = 2$ are equivalent.

4.2. Limitations and possible extensions

While this model offers some first insights into the firms' incentives within mandatory deposit-refund systems, many of its assumptions are overly restrictive and should eventually be relaxed to obtain more reliable results.

Monopolization in the asymmetric subgames only works because the firm with a non-standard bottle does not have an incentive to undercut, and therefore, neither does the firm with standardized packaging. Adding a third firm will likely again incentivize the firm with standardized packaging to start undercutting. Hence, extending the model to $n \geq 3$ firms may offer additional insight. Nonetheless, it appears that if all firms in a market pick a differentiated bottle, they are able to act as local monopolists.

The arguably most problematic assumption is consumer myopia, as consumers may prefer products in standardized packaging if they expect the prices to be relatively lower in the future. This may be particularly interesting in asymmetric subgames of a game with more than two firms.

Additionally, the model only has two periods. This means the firms can only reap monopoly profits off their market shares once. Extending the game to multiple periods may allow us to drop the parametric restriction imposed on consumers' valuation.

Moreover, all bottles get returned in the model as consumers purchase twice at the same firm in equilibrium. If the distribution on the unit interval is thought of more in terms of taste rather than geographically, we could consider some consumer shifts along the interval each period.

5. Conclusion

This thesis analyzed the firms' choice of (non-)standard bottles in duopolistic markets with heterogeneous goods and mandatory deposit-refund systems for bottles. The model assumed infinitely patient, forward-looking firms and myopic consumers.

Both firms have an incentive to pick a non-standardized bottle as it allows them to lock some consumers in and therefore charge higher prices. Consequently, both firms picking a standardized bottle is the only bottle choice combination that cannot be sustained as a subgame perfect equilibrium.

Moreover, a single firm choosing a differentiated bottle already gives both of them monopoly power over their market shares in $\tau = 2$. Hence, the equilibria where either firm or both firms pick a differentiated bottle are equivalent. I expect this to break down once a third firm is added to the model. Nevertheless, all firms picking a differentiated bottle likely leads to monopolization irrespective of the number of firms in the market.

All three equilibria lead to a decrease in consumer welfare and simultaneously to higher profits compared to no deposit-refund system. The findings suggest that deposit-refund systems should only be implemented in a standardized manner. To conclude, whenever firms are allowed to create incompatibilities, deposit-refund systems lead to an increase in market power.

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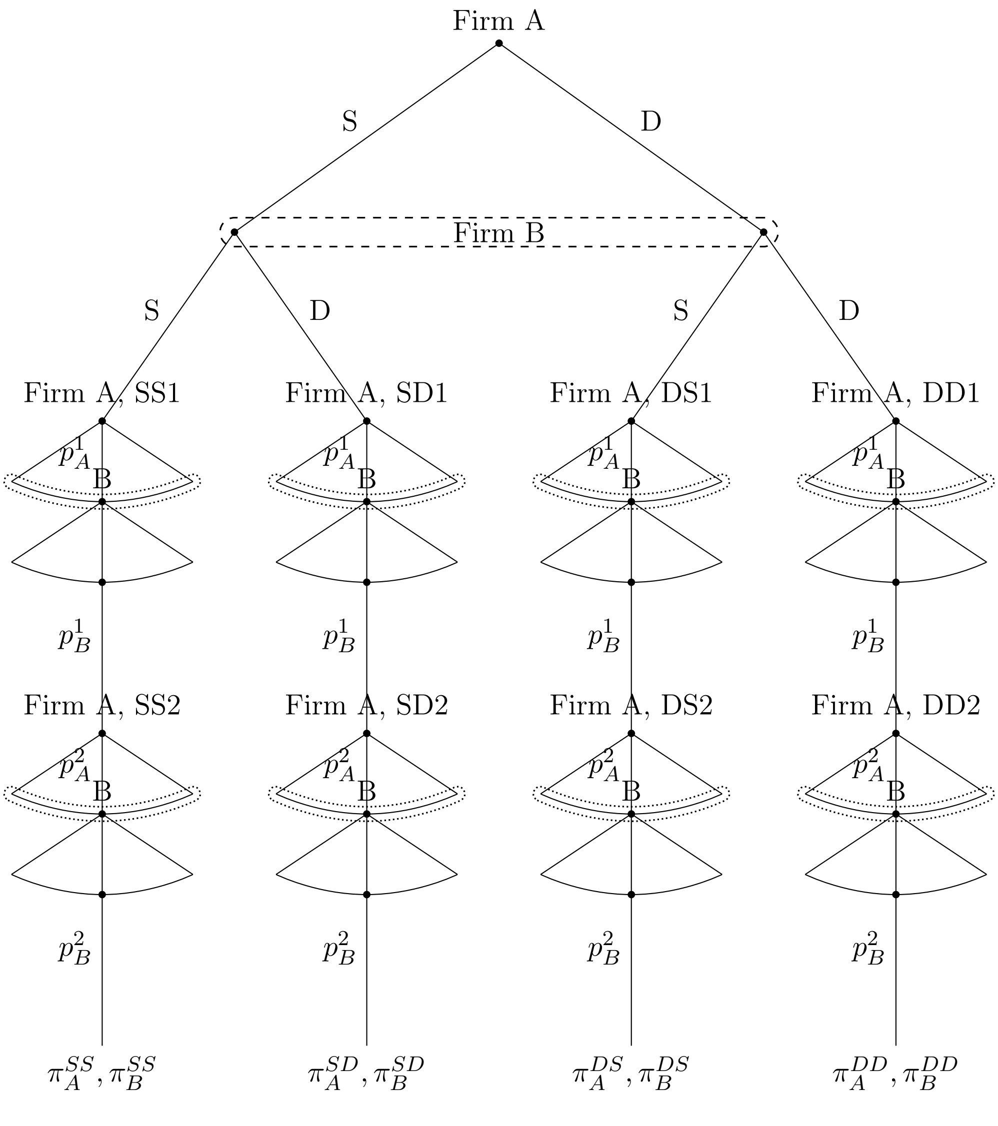
A. Game tree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