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Preinstalled application policies of smart device firms

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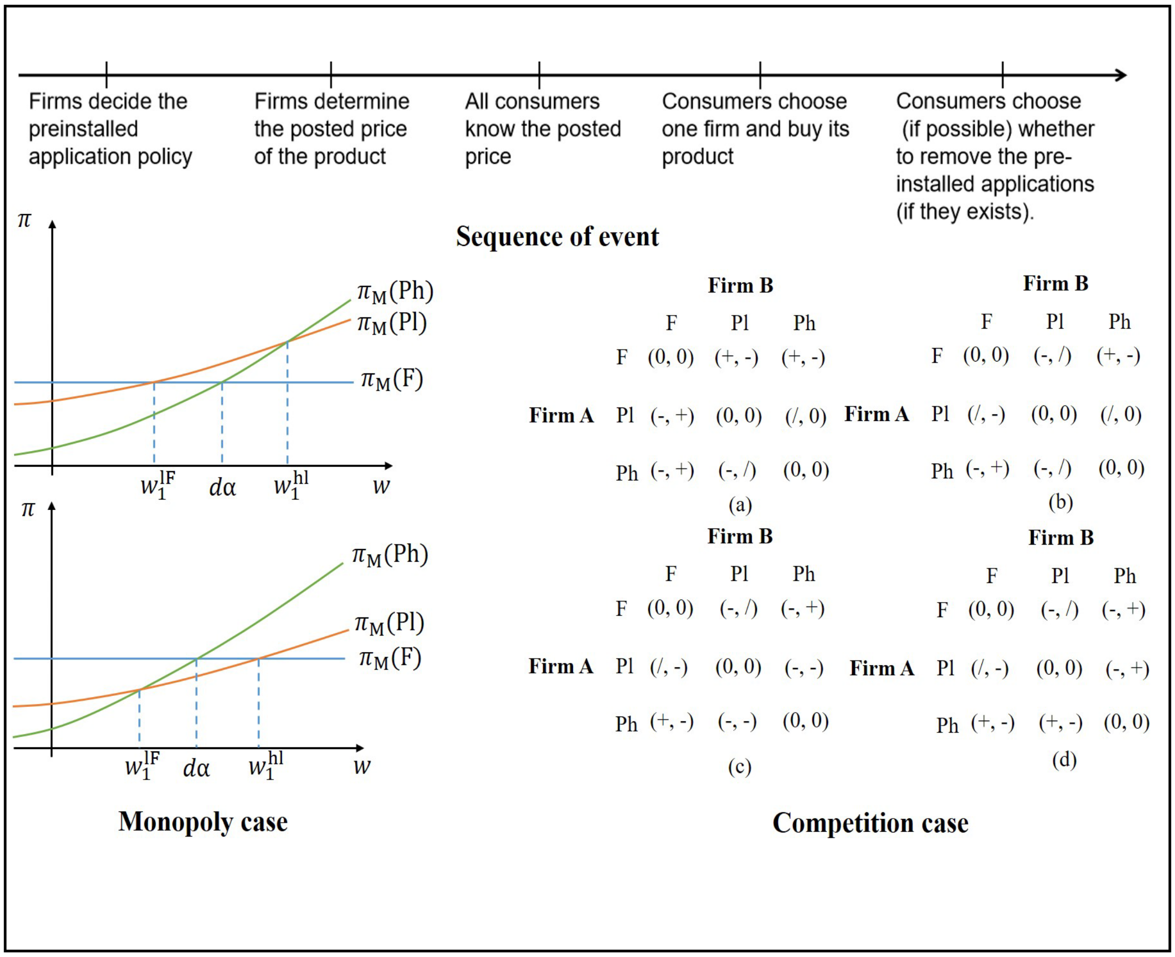
Graphical abstract



Preinstalled applications and higher uninstall thresholds are not always beneficial for smart device firms.

Public summary

- Preinstalled applications and higher uninstall thresholds are not always beneficial for smart device firms.
- Compared to the monopoly situation, the preinstallation strategy of the firm in a competitive situation is more sensitive to marginal preinstallation revenue.
- The removal of applications by expert consumers may not always hurt the firm's interests; they may also increase profits for the firm in a monopoly.

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Abstract: Recent technological advancements in smart devices have paved the way for a booming mobile commerce industry. As smart device vendors launch products with a rich variety of business applications, it is critical for all stakeholders to understand the attitudes of different vendors toward preinstalled applications in the smart device industry. We address this issue by exploring an analytical model for preinstalled application policies. Specifically, we study how to choose an optimal policy in a market with hypercritical consumers who have disutility from preinstalled applications, and expert consumers who have removal knowledge. The results show that, as marginal preinstallation income increases, firms tend to force more consumer segments to use preinstalled applications. By comparing monopolistic and competitive situations, we find that the advantages of the policy change are different, and competitive firms prefer to adopt more stringent policies than monopolistic firms when the marginal preinstallation income is smaller. The initiative of expert consumers introduced new findings to the research. The increase in such consumers may lead to an increase in the profits of monopolistic firms when they adopt a preinstallation policy with a low removal threshold, but this has no impact on the profits of competitive firms. Additionally, an increase in such consumers will lead competitive firms to choose to bundle applications when the marginal preinstallation income is smaller and the impact on monopolistic firms' policy decisions is more complex.

Keywords: bundling; preinstalled app; game theory
CLC number: F272.3 **Document code:** A

1 Introduction

Consumers often face the problem of having too many preinstalled applications loaded on smart devices. Preinstalled applications refer to those installed in advance on smart devices, which contain negative features that may reduce the consumer experience. Examples include tool, entertainment, social, e-commerce, security, and game applications. These applications may be system applications owned by smart device firms or third-party applications provided by developers. Mandatory preinstallation applications generally include the following three features: first, their details are not explicitly stated and do not require user consent. Second, they are irrelevant to the maintenance of the basic operational functions of the original system. Finally, they are usually written into devices' firmware and cannot be deleted or unloaded by conventional methods.

Preinstalled applications damage product quality to a certain extent because they have three negative characteristics. The first one is concealment and malice. Preinstalled applications often permit the loss of privacy and security, such as forcibly displaying content that users do not want to see, illegally or excessively collecting user data, hindering data deletion, permitting data sharing between apps, and even carrying viruses[1]. Common malicious operations include advertising, which displays advertisements that users do not want to see and that collect user behavior data in cyberspace; espionage, which remotely monitors behavior without user consent; intimidation, which notifies users of problems that do not exist and provides them with false solutions; and backdoors, which allow attackers to control mobile devices unnoticed. The second one is feature redundancy. Although studies have shown that preinstalled applications were originally designed to provide rich features and meet the needs of different end-user markets[2], if the number of features exceeds a certain requirement, this richness becomes redundant. Bloatware leads users to unnecessary information, visual confusion, abnormal interface design, excessive learning time, and system vulnerability[3]. Preinstalled applications also occupy device memory, consume data traffic, and negatively affect some system operations. Kim et al.[4] believe that users associate negative attributes, such as product slowness with preinstalled software, resulting in a negative user experience. The third is a unilateral compulsion. Ultimately, the main contradiction between firms and users comes from the fact that firms can independently choose preinstalled applications, while users may not because redundant preinstalled applications cannot be removed by conventional means. As a smart device provider service, preinstallation violates the voluntary principle of both parties in the transaction and deprives users of their independent choice. The unilateral coercion of suppliers replaces the consensus of negotiation between the two parties and disrupts the market transaction orders, which deeply troubles users.

There are differences in consumer acceptance of these negative characteristics. Elahi et al.[5] found in an online survey that some consumers feel that preinstalled software is useful to some extent. However, for other consumers, preinstalled software destroys their experience of using smart devices to a certain extent, so users call it bloatware, scrap, and even malware. Some consumers (such as elderly consumers or consumers who know little about rooting technology) hate these applications, but they have no way of removing them and can choose only to endure them. Eliminating bloatware through rooting may lead to security vulnerabilities, unstable operating systems, and invalid product warranties[1]. Nevertheless, a large number of consumers still try to root. In the long-term struggle between consumers and smart device firms equipped with preinstalled software, consumers' attitudes toward preinstalled software and the use of unloading technologies cause them to master a certain initiative in this struggle, so their feelings and abilities have become important considerations in our model. In this study, based on the above factors, we divide consumers into three segments: tolerant consumers who do not care whether products are bundled with applications; hypercritical non-expert consumers who hate preinstalled applications but can choose only to tolerate them; and hypercritical expert consumers who hate preinstalled applications and remove them to the greatest possible extent.

One focus of this study is the attitude of competitive firms toward these applications that essentially damage quality but can result in additional revenue. For smart device firms in a competitive situation, when the cost is at a certain level, the price of smart devices continues to decline and the hardware profit is infinitely diluted, so firms seek subsidies through preinstalled software. Preinstallation revenue is derived from three main sources. First, third-party application suppliers pay the installation fee to smart device firms, which may be in the form of providing a fixed commission for each unit of an activated product. Second, the applications developed by smart device firms have great strategic value for the firms' business expansion and profitability. Such as a finance store and a brand store, which can help earn further profits. Finally, in addition to the direct benefits, the indirect benefits resulting from resource replacement also impel firms to choose preinstallation. For example, Microsoft has reached extensive cross-licensing agreements with Samsung, HTC, and other manufacturers①. In exchange for preloading Office series applications on smartphones, Microsoft provides some Android-related patent licenses to smartphone manufacturers. Although the forms and sources of preinstallation revenue are different, ultimately, users' behavior is the fundamental reason for their value. Smart device firms claim that they include preinstalled applications to serve the diversified needs of different end-user market segments[2, 6]. Users' participation plays a crucial role in product value creation, such as application access, advertising exposure, product purchases resulting from users' behaviors, and users' drainage through application internal functions and modules. Therefore, the model in this paper considers that each consumer who does not completely remove the preinstalled application can contribute a marginal amount of preinstalled revenue to smart device firms.

Another focus of this paper is consumers' attitudes toward preinstalled applications and consumers' subjective initiative to react to smart device firms.

Although most firms choose to preinstall, the removal threshold settings of preinstalled applications differ. A survey conducted by the Shanghai Consumer Protection Commission in 2015 showed that each of the 19 new smartphone samples had at least 27 preinstalled applications②. Those in Gionee GN9000l, Samsung SM-N9008S, and Apple iPhone6 plus could not be uninstalled. Oppo X9007 had the most preinstalled applications at 71, 47 of which could not be uninstalled. A large number of consumer complaints have also forced some firms to soften their preinstalled application policies and reduce the removal threshold. For example, Apple's CEO Tim Cook said in an interview with BuzzFeed that users will be allowed to uninstall some preinstalled iOS applications. In the future, Apple will develop an appropriate way to allow users to freely decide whether to delete applications that do not affect system functions. Lenovo announced that it would use preinstalled software as little as possible. In addition, OnePlus has said that it will provide consumers with a minimalist operating system as close as possible to the original system and even cooperate with rooting firms to help consumers more easily obtain the root access rights of the device. On the one hand, these facts show that smart device manufacturers have different attitudes toward preinstalled applications. However, consumers' behaviors can have a certain impact on firms' preinstalled application policy choices. Cavusoglu et al.[7] showed that jailbreaking affects the preinstalled commercial value by third-party software suppliers and the preinstallation revenue of a monopolistic firm. To a certain extent, this finding explains the widely different positions of smart device manufacturers on bloatware.

The above research considers the adoption of preinstalled application policies by smart device manufacturers in a monopolistic situation. Considering the actual market situation of smart device firms, we extend the research to the competitive situation and consider how heterogeneous consumers affect firms. This work mainly addresses the following questions: (i) How do smart device firms choose their preinstalled application policies? (ii) How does competition affect firms' policy choices and profits? (iii) How do expert consumers affect preinstalled application policies and product pricing? The structure of the study is as follows. The second section reviews the relevant literature. The third section develops an analysis model. In the fourth section, we discuss the equilibrium policy of competitive firms and analyze and compare monopolistic with competitive firms. The results show that, as marginal preinstallation income increases, firms gradually allow consumers in more market segments to obtain products equipped with preinstalled applications. Competitive firms have the same policy change advantage points, which leads

①https://www.techradar.com/uk/news/phone-and-communications/mobile-phones/microsoft-and-samsung-sign-cross-licensing-patent-deal-1030063

②http://finance.cnr.cn/315/gz/20150704/t20150704_519073134.shtml

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competitive firms to adopt the same preinstalled policies.

2 Literature review

Our research is related to three previous research directions. We mainly discuss the negative effects of preinstalled applications on consumers. McDaniel[6] defined a large number of unnecessary and unavoidable applications received by users through new smartphones as bloatware. Bloatware is an important alternative distribution carrier for unpopular applications[8]. Alam et al.[9] studied bloatware from the perspectives of security, privacy, energy, and storage. This paper puts forward the classification of expansion software and identifies some hazards of expansion software problems to smartphone systems. Elahi et al.[10] provided the results of a user study to investigate the practicability of bloatware in users' personal and professional lives. This paper analyzes users' dependence on programs and related user expectations and discusses whether these applications are valuable assets and whether users should give up control over their data and privacy in exchange. The privacy uncertainty of an application has a significant impact on potential users' willingness to use the application and the perceived risks associated with its use, as well as the willingness to pay[5]. An empirical study by Elahi et al.[5] investigated the privacy, security, and trust issues of preinstalled applications on Android devices and evaluated their utility statements and the functional requirements coverage of different end-user market segments. The results provide some basis for the consumer segmentation in this paper. Suarez-Tangil et al.[11] studied how malware on smart devices has evolved on the most popular platforms over the past few years and the latest progress in detection technology. Ref. [7] is particularly relevant to this study. This study is the first to consider the modification of smart devices initiated from the consumer end and how this behavior affects the willingness to pay third-party application suppliers, then affects the preinstallation decision of monopolist firms. In contrast, considering that the preinstallation mode of some firms (such as Apple which is in a strong position in the supply chain) is not influenced by the remuneration provided by third-party application suppliers, we focus on the average marginal preinstallation income generated by consumers' use. This income may be derived from the additional revenue caused by advertising share, traffic guidance, and other consumer activities. In addition, considering consumers' attitudes toward preinstalled applications and the possible impact of their technical abilities on product choice, we subdivide consumers into three segments.

As firms' preinstallation behaviors reduce the utility of consumers to some extent and this kind of behavior is very common, our study relates to a body of research on the intentional damage to utility. Consumers sometimes cannot obtain the highest quality products because firms may destroy parts of the products and reduce their quality to carry out price discrimination so they may obtain Pareto improvement[12]. This kind of damage is easy to implement on information products, such as through the creation of low-quality versions by removing/disabling/reorganizing the highest quality versions. This policy is called versioning[13]. A study by Bhargava and Choudhary[14] shows that if high-end consumers have a lower relative valuation of lower-quality products than low-end consumers, then the versioning of information products is optimal. However, higher quality may reduce consumer utility, considering no free disposal (NFD) attributes and feature creep. Chellappa and Shivendu[15] showed that information products exhibit NFD attributes because they emphasize consumer participation, which requires time and energy, resulting in an essentially negative effect on consumption: more is not necessarily better.

Chellappa and Mehrab[16] characterize the cost of use when consuming information products, indicating that consumers' negative effects on quality play an important role in consumer segmentation. Marginal costs (including use costs) are the only reason for versioning[17].

The literature on feature creeping shows that many products contain some features that most consumers do not use. This situation requires consumers to invest much energy in learning, thereby reducing the usability of products and leading to lower consumer satisfaction[13], while firms can manage consumer bias by strategically adjusting prices, product functions, or usability[18]. Bhargava and Feng[19] find manufacturers can filter consumers by forcibly binding a component that consumers don't want to reduce consumer valuation. Different from the above research, the utility damage here is not directly caused by reducing product quality or improving use costs but by bundling components that dissatisfy some consumers to reduce their willingness to pay.

Products with preinstalled applications are a form of bundled sales. Geng[20] studied the optimality of the pure bundling of information products with decreasing values and showed that pure bundling is optimal when the value slowly decreases. Shugan et al.[21] observed that different industries choose to bundle at different ends of the product line and explained this phenomenon with core product differentiation. Cui et al.[22] studied the complementarity and substitution between the unbundling policies of ancillary services and the price discrimination policy and showed that if consumers' valuation of the primary and ancillary services is low, the two policies are complementary. Jedidi et al.[23] established a model to capture the continuous heterogeneity in the joint reservation price distribution of products and bundles and used the model estimation to select the optimal product line pricing strategy. Prasad et al.[24] analyze whether a firm with a monopoly should choose a mixed bundling strategy and its variants or retention pricing strategy when there are short-sighted and long-sighted consumers in the market. The results show that retention pricing is more profitable as long as there are moderately short-sighted consumers in the market. The psychological account effect shows that consumers are more willing to integrate losses into a single bundle price in the form of price information[25]. The empirical results of this paper extend the psychological account effect to the context of price bundling. Some theoretical studies also consider that bundling reduces consumers' valuation of products. Chen et al.[26] studied how valuation discount affects decision optimization in distribution channels and pointed out that due to the existence of valuation discount, a hybrid bundling strategy does not always perform better than a pure component

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JUSTC, **2022**, 52(11): 5

strategy.

Otherwise, substitutions occur. Shulman and Geng[27] studied how bundling affects the profits of competitive firms when consumers are boundedly rational. This study refers to its setting of consumer segments in modeling. In our study, however, unbundling is initiated by consumers, and consumers who can modify their devices will choose to do so when the cost of rooting is lower.

3 Model

3.1 Firms

Consider a linear city, in which two competing firms $j \in \{A, B\}$ are located at $x_A = 0$ and $x_B = 1$, the consumer reservation utility of each firm's offerings is v. The marginal costs of the two products are the same, c. They also have the same market power or ability to obtain marginal preinstallation income, which is captured by $w (0 < w < 1)$. Some consumers have a negative utility on preinstalled applications, captured by $d (0 < d < 1)$. To be practical, the valuation and cost should satisfy $v \geqslant 2c \gg d, w$. For example, the smartphone disassembling agency of tech insights disassembled the products and calculated the material cost based on the current market price. It was found that the actual price of most brands was twice higher than the material cost. In addition, consumers' negative utility and preinstallation income for products will be far less than the retained value of products, which is in line with common sense.

Before the products are produced, the firms will decide whether to preinstall applications and the difficulty of unloading them. Together, these two parts constitute a preinstalled application policy. When the firms choose not to preinstall apps, there is no difference in the unloading difficulty in our settings. This policy is called the preinstallation-free (F) policy. When the firms choose to preinstall applications, if the firms allow the consumers to unload some preinstalled applications, the difficulty of unloading them is set very low so some consumers can obtain nonnegative utility from the removal behavior. This policy is called the preinstallation low-unloading-cost (Pl) policy. If the firms do not allow consumers to unload the preinstalled applications, they will set a high removal threshold. That is, the cost is higher than the additional utility if consumers unload the applications, so no consumer chooses to unload the preinstalled applications. This kind of policy is called the preinstallation high-unloading-cost (Ph) policy. Let P_j denote the policy adopted by firm j, and $P_j \in \{F, Pl, Ph\}$. Thus, nine possible policy combinations result: (F, F), (Pl, F), (Ph, F), (F, Pl), (Pl, Pl), (Ph, Pl), (F, Ph), (Pl, Ph), (Ph, Ph).

3.2 Consumers

Consumer heterogeneity is reflected in three dimensions: the first dimension is the different tastes of the product, which are captured by $\theta \sim U[0,1]$. Consumer i located in θ_i will cost $t\theta_i$ (or $t(1-\theta_i)$) to access the product of firm A (or B), where t is the transportation cost. The second dimension is the different attitudes toward the preinstalled applications. We allow the proportion α of consumers who dislike preinstalled applications to have negative utility d on products with preinstalled applications. We refer to them as hypercritical consumers. The remaining proportion, $(1-\alpha)$, of consumers do not consider whether the products have preinstalled applications, and their disutility is zero. This type of consumer is tolerant, may be accustomed to having preinstalled applications on their products, and may think it is reasonable or may not be vulnerable to interference from such applications. Consumers are heterogeneous in their ability to reverse the damage caused by preinstalled applications. The third dimension is the different abilities to root. The percentage β of consumers who have a removal experience or relevant knowledge is willing to spend a certain cost on removing the preinstalled applications. Therefore, when firms adopt the Pl policy, they choose to reduce the damage by unloading the applications; the remaining $(1-\beta)$ consumers are non-expert consumers. Although the removal threshold set by firms is very low, non-expert consumers still have difficulty in uninstalling applications. Examples include some children and elderly users or users who are reluctant to spend their time looking for ways to unload applications. If firms do not choose a preinstallation-free policy, they can tolerate it. Thus, we have three segments, as listed in Table 1, where

$$M_j = \begin{cases} 1, \text{ if } \quad P_j = \text{Ph}; \\ 0, \text{ else.} \end{cases}$$

$$N_j = \begin{cases} 1, \text{ if } \quad P_j = \text{F}; \\ 0, \text{ else.} \end{cases}$$

Table 2 shows the parameters and variables in the model.

3.3 Timeline

As the timeline (Fig.1) shows, the sequence of the game is as follows: in stage 1, the firms decide the preinstalled application policy. In stage 2, the firms determine the posted price of the product. All consumers know the posted price in stage 3. In stage 4, consumers choose one firm and buy its product. In stage 5, consumers choose (if possible) whether to remove the

Table 1. Description of consumer segment.

	α fraction $d_i = d$	$(1-\alpha)$ fraction $d_i = 0$
β fractions have access to rooting	Hypercritical expert segment $\alpha\beta$ utility: $v - t\lvert\theta_i - x_j\rvert - p_j - dM_j$	Tolerant segment $1-\alpha$ utility: $v - t\lvert\theta_i - x_j\rvert - p_j$
$(1-\beta)$ fractions have no access to rooting	Hypercritical nonexpert segment $\alpha(1-\beta)$ utility: $v - t\lvert\theta_i - x_j\rvert - p_j - dN_j$	

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Table 2. Parameter and decision variables.

Symbol	Definition
v	Valuation of product
c	Marginal cost of product
w	Marginal preinstallation income
x_j	Location of product j
p_j	Price of product j
P_j	Policy of product j
t	Transportion cost for consumers
d	Disutility of product with preinstalled applications
θ_i	Consumer i's taste parameter
D_j	Demand of firm j
α	Proposition of consumers who suffer damage from preinstalled applictions
β	Proposition of consumers who can remove preinstalled applictions
T	Tolerant segment
E	Hypercritical expert segment
N	Hypercritical nonexpert segment

preinstalled applications (if they exist).

4 Results and discussion

We analyzed this model using backward induction. In the following subsection, we discuss firms' preinstalled application policies in the two cases. In the benchmark, we focus on the special case of a monopolistic firm. We also compare monopoly and symmetric competition to illustrate the impact of competition better.

We examine three consumer segments: $1-\alpha$ tolerant consumers, $\alpha\beta$ hypercritical expert consumers, and $\alpha(1-\beta)$ hypercritical non-expert consumers, as in Table 1. To our knowledge, this is the first study on preinstalled application policies that considers all three segments. The results provide new insights into the literature when both firms serve all three segments in equilibrium.

4.1 Benchmark: Monopolistic firm

Consider the case of a monopolistic firm as a benchmark, which means there is only one firm located in $x=0$. First, we calculate the marginal consumer of each market segment who is indifferent between purchasing the product and not. For instance, if the firms adopt the Ph policy, the marginal expert consumer satisfies

$$v-t\theta^{\mathrm{E}}-p_{\mathrm{M}}-d=0. \tag{1}$$

Thus, the consumer located at $(v-p_{\mathrm{M}})/t$. Similarly, we can obtain other marginal consumers under the three policies. Then the product demand is

$$D_{\mathrm{M}}=(v-p_{\mathrm{M}}-S_{\mathrm{M}}(P)d)/t,$$

where $S_{\mathrm{M}}=\begin{cases}0, & \text{if } P=\mathrm{F};\\ \alpha\beta, & \text{if } P=\mathrm{Pl};\\ \alpha, & \text{else.}\end{cases}$

The profit is

$$\pi_{\mathrm{M}}(P)=(p_{\mathrm{M}}-c)D_{\mathrm{M}}+w((1-\alpha)\theta^{\mathrm{T}}+\alpha\beta\theta^{\mathrm{E}}M_{\mathrm{M}}+\alpha(1-\beta)\theta^{\mathrm{N}}N_{\mathrm{M}}). \tag{2}$$

Maximizing Eq. (2), we obtain the optimal prices and profits under the three policies, as Lemma 4.1 shows.

Lemma 4.1. The monopolistic firm (i) charges the price of $\frac{v+c}{2}$ and earn a profit of $\frac{(v-c)^2}{4t}$ if the F policy is adopted, (ii) charges the price of $\frac{v+c-d\alpha(1-\beta)-w(1-\alpha\beta)}{2}$ and earn a profit of $\frac{(v-c-d\alpha(1-\beta)+w(1-\alpha\beta))^2-4dw\alpha^2(1-\beta)\beta}{4t}$, if the Pl policy is adopted and (iii) charges the price of $\frac{v+c-d\alpha-w}{2}$ and earn a profit of $\frac{(v-c-d\alpha+w)^2}{4t}$ if the Ph policy is adopted.

Proposition 4.1. (i) If $w_{\mathrm{M}}^{\mathrm{lF}}<w_{\mathrm{M}}^{\mathrm{lh}}$, the monopolistic firm adopts the F policy if $w\in[0,w_{\mathrm{M}}^{\mathrm{lF}})$, the Pl policy if $w\in[w_{\mathrm{M}}^{\mathrm{lF}},w_{\mathrm{M}}^{\mathrm{lh}})$, and the Ph policy if $w\in[w_{\mathrm{M}}^{\mathrm{lh}},1]$;

(ii) If $w_{\mathrm{M}}^{\mathrm{lF}}\geqslant w_{\mathrm{M}}^{\mathrm{lh}}$, the monopolistic firm adopts the F policy if $w\in[0,\alpha d)$, and the Ph policy if $w\in[\alpha d,1]$.

Proposition 4.1 illustrates how monopolistic firm obtains the optimal policy. $w_{\mathrm{M}}^{\mathrm{lF}}$, $w_{\mathrm{M}}^{\mathrm{lh}}$ are nonnegative roots of $\pi_{\mathrm{M}}(\mathrm{Pl})=\pi_{\mathrm{M}}(\mathrm{F})$ and $\pi_{\mathrm{M}}(\mathrm{Pl})=\pi_{\mathrm{M}}(\mathrm{Ph})$, respectively. The relationship between them can be used to estimate whether firms will adopt the Pl policy. Proposition 4.1 (i) shows that if the latter is larger, when w is less than $w_{\mathrm{M}}^{\mathrm{lF}}$, firms obtain the maximum profit under the F policy. When w is between the two roots, firms obtain the maximum profit under the Pl policy, and when $w>w_{\mathrm{M}}^{\mathrm{lh}}$, firms obtain the maximum profit under the Ph policy. Proposition 4.1 (ii) shows that if the latter is larger, the Pl policy will never be the optimal policy.

When $w<\alpha d$, the firm will obtain greater profits by adopting the F policy, and if vice versa, the firm will obtain the highest profits by adopting the Ph policy.

Fig. 2 illustrates both Proposition 4.1 (i) and (ii) numerically. Proposition 4.1 answers two questions. First, is it always good for firms to sell smart devices with preinstalled applications? Different smart device industries have widely different preinstallation levels. For example, smart cars and

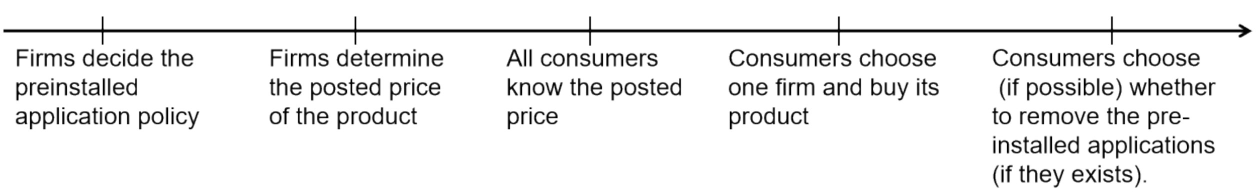

Fig. 1. Timeline.

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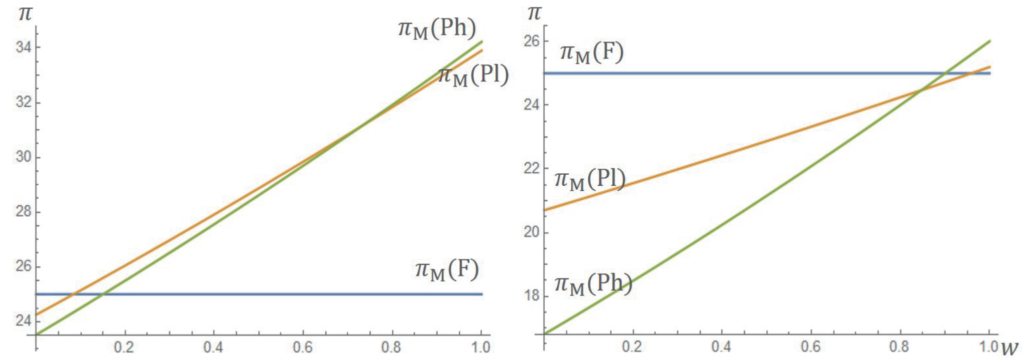

(a) $v=10, c=5, d=\frac{3}{4}, \alpha=\frac{1}{5}, \beta=\frac{1}{2}$ (b) $v=10, c=5, d=1, \alpha=\frac{9}{10}, \beta=\frac{1}{2}$

Fig. 2. Numerical demonstration of Proposition 4.1.

TVs have fewer preinstalled applications than smartphones. In addition, the installation level of preinstalled applications in the same industry differs in different years. For example, the common phenomenon in the early years of the smart TV industry was that the prosperity of the hardware could not hide the lack of software. In recent years, preinstalled applications have become too numerous, and consumers have become eager to find ways to uninstall. This situation is because preinstalled applications have two effects on firms, a positive direction (i.e., preinstalled applications can bring additional revenue) and a negative indirect effect (i.e., the demand of hypercritical consumers will decline). Therefore, firms must reduce retail prices to alleviate consumer loss. When the indirect effect is dominant, firms tend to adopt the F policy, while when the direct effect is dominant, firms will choose the preinstallation policy. That is, when the software industry is more prosperous, firms will obtain more preinstallation revenues and choose to preinstall more applications. Second, is it always beneficial for firms to reduce the removal threshold of preinstalled applications? Many practical examples show wide industry differences in the threshold for removing preinstalled applications. For example, preinstalled applications are usually easier to remove on computers than smartphones. Moreover, the removal threshold differs even in the same industry. For example, the preinstalled application unloading for iOSs requires jailbreaking, which may lead to system instability or warranty failure. The removal threshold is thus very high. Meanwhile, root permission is easier to obtain with the Android system, and the removal threshold is relatively low.

From the answer to the first question, it is obvious that firms' preinstallation policies are driven by preinstallation revenues. However, Proposition 4.1 (i) indicates that when firms choose to adopt the preinstallation policy, the preinstallation revenue will not always be maximized, that is, not all buyers will use the preinstalled applications.

At this time, compared with the situation of squeezing preinstalled income from hypercritical consumers, the outflow of consumers will result in a greater loss of main product revenue. Therefore, firms adopt a compromise approach, allowing some hypercritical consumers to uninstall applications (i.e., hypercritical expert consumers) and increasing product sales at the cost of losing some preinstallation revenue. Proposition 4.1 (ii) shows that regardless of the marginal preinstallation income, the monopolistic firm will not adopt the Pl policy. The composition of consumer segments plays a crucial role in the firms' strategic choice, which is further analyzed in Section 4.3.

4.2 Competitive firm

Similar to the monopolistic case, to derive the number of consumers who purchase products in Stage 3, we identify the marginal consumer in each segment that is indifferent between the two products. If firm A adopts the Ph policy and firm B adopts the F policy and firm prices (p_A,p_B), then the marginal consumer in the technical segment satisfies

$$v - t\theta^E - p_A - d = v - t(1-\theta^E) - p_B,$$

and is thus located in $\theta^E = (p_B - p_A - d + t)/(2t)$. All consumers in the technical segment with $\theta < \theta^E$ ($\theta \geqslant \theta^E$) purchase the product from firm A (firm B). Similarly, we can obtain the indifferent consumers of the three segments under the nine policy pairs, and the demand for each firm's product is

$$D_j(P_A, P_B) = \frac{1}{2} + I_j \frac{p_B - p_A - S(P_A, P_B)d}{2t}, \tag{3}$$

$$I_j = \begin{cases} 1, \text{ if } j = \text{A}; \\ -1, \text{ else.} \end{cases}$$

$$S(P_A, P_B) = \begin{cases} 0, \text{ if } P_A = P_B; \\ \alpha, \text{ if } P_A = \text{Ph}, P_B = \text{F}; \\ \alpha(1-\beta), \text{ if } P_A = \text{Pl}, P_B = \text{F}; \\ \alpha\beta, \text{ if } P_A = \text{Ph}, P_B = \text{Pl}; \\ -\alpha, \text{ if } P_A = \text{F}, P_B = \text{Ph}; \\ -\alpha(1-\beta), \text{ if } P_A = \text{F}, P_B = \text{Pl}; \\ -\alpha\beta, \text{ if } P_A = \text{Pl}, P_B = \text{Ph}. \end{cases}$$

$P_A, P_B \in \{\text{Ph, Pl, F}\}$.

Therefore, the profit for firm j is given by

$$D_j(P_A, P_B) = \frac{1}{2} + I_j \frac{p_B - p_A - S(P_A, P_B)d}{2t}, \tag{4}$$

$$D_j^s = \begin{cases} \theta^s, \text{ if } j = \text{A}; \\ 1-\theta^s, \text{else.} \end{cases}$$

$j \in \{\text{A, B}\}, s \in \{\text{T, E, N}\}$.

DOI: 10.52396/JUSTC-2022-0012
JUSTC, **2022**, 52(11): 5

Table 3. Equilibrium price of competitive firm.

	F	Pl	Ph
F	$t+c$, $t+c$	$\frac{3t+3c+d\alpha(1-\beta)-(1-\alpha\beta)w}{3}$, $\frac{3t+3c-d\alpha(1-\beta)-2(1-\alpha\beta)w}{3}$	$\frac{3t+3c+d\alpha-w}{3}$, $\frac{3t+3c-d\alpha-2w}{3}$
Pl	$\frac{3t+3c-d\alpha(1-\beta)-2(1-\alpha\beta)w}{3}$, $\frac{3t+3c+d\alpha(1-\beta)-(1-\alpha\beta)w}{3}$	$t+c-(1-\alpha\beta)w$, $t+c-(1-\alpha\beta)w$	$\frac{3t+3c+d\alpha\beta-(3-2\alpha\beta)w}{3}$, $\frac{3t+3c-d\alpha\beta-(3-\alpha\beta)w}{3}$
Ph	$\frac{3t+3c-d\alpha-2w}{3}$, $\frac{3t+3c+d\alpha-w}{3}$	$\frac{3t+3c-d\alpha\beta-(3-\alpha\beta)w}{3}$, $\frac{3t+3c+d\alpha\beta-(3-2\alpha\beta)w}{3}$	$t+c-w$, $t+c-w$

Maximizing each firm's profit, we obtain the equilibrium price and profit under each policy, as shown in Table 3.

Lemma 4.2. Competitive firms always adopt symmetrical policies in equilibrium. The price charged by firm j under (F,F) is $t+c$, that charged under (Pl, Pl) is $t+c-(1-\alpha\beta)w$, and that charged under (Ph, Ph) is $t+c-w$. Finally, under the three equilibria above, the profits of the two firms are $\frac{t}{2}$.

Lemma 4.2 illustrates the following three points. First, the preinstalled application policies of competitive firms are always the same as their prices and profits. Second, although the same policy is adopted in the case of competition, the equilibrium price decreases gradually as the removal threshold increases. Third, although the equilibrium price is different, firms' final equilibrium profits are the same. Proposition 4.2 shows that firms reach equilibrium.

Proposition 4.2. If $w\in\left[0,\frac{\alpha(1-\beta)d}{1-\alpha\beta}\right)$, firms will not preinstall apps on products; if $w\in\left[\frac{\alpha(1-\beta)d}{1-\alpha\beta},d\right)$, firms will install apps but will allow some consumers to remove the preinstalled apps (i.e., set lower removal thresholds); if $w\in[d,1]$, firms will install apps and forbid all consumers from removing the preinstalled apps (i.e., set high removal thresholds).

Competing firms adopt the same policy. Proposition 4.2 shows that as marginal preinstallation income increases, firms will adopt a preinstallation policy and gradually raise the removal threshold. However, the counterintuitive point is that, even with the preinstallation policy, firms cannot obtain additional benefits in the equilibrium. Owing to fierce competition, firms will fully subsidize marginal income to consumers in the form of price reductions, resulting in the same profit as the F policy. Although allowing more consumers to use preinstalled applications will not increase the firm's profits in equilibrium, when there are two symmetrical equilibria, the preinstallation policy always weakly dominates the preinstallation-free policy and the high rooting cost always weakly dominates the low rooting cost. In other words, firms tend to allow more people to use preinstalled applications. This is because, in equilibrium, firms that allow fewer consumers to use preinstalled applications will always suffer more damage.

To better illustrate the impact of competition, we compare monopolies and competitions, and draw two corollaries.

Corollary 4.1. (ⅰ) Whether the firm is monopolistic or competitive, the price does not decrease with w.

(ⅱ) The profit of a monopolistic firm does not decrease in w and the equilibrium profit of competitive firms is unrelated to w.

Corollary 4.1 shows that, regardless of the consumer segment composition, an increase in marginal preinstallation income is always conducive to the profit of a monopolistic firm without affecting the profits of competitive firms. This is because when firms adopt the F policy, they cannot obtain preinstallation revenues. At this time, the marginal preinstallation income is unrelated to price and profit.

When firms adopt the preinstallation policy, only part of the marginal preinstallation income obtained by the monopolistic firm subsidizes consumers in the form of a price discount, whereas for competitive firms, all marginal preinstallation income acts as a consumer subsidy.

This result shows that, under a competitive situation, the price war will lead to a final preinstallation revenue of 0. For monopolistic firms, although raising the removal threshold will reduce the equilibrium price, on the one hand, the market segments using preinstalled applications have increased. On the other hand, the total number of consumers has increased, so the total profits of the firms have increased.

Compared with monopoly, competition also affects a firm's policy adoption, as Corollary 4.2 shows.

Corollary 4.2. In most cases, compared with monopolistic firms, competitive firms adopt a policy of forcing more segments to use preinstalled applications in advance (i.e., when marginal preinstallation income w is smaller).

Corollary 4.2 indicates that if a monopolistic firm adopts the Pl policy (i.e., Proposition 4.1 (ⅱ)), two advantages result from the policy change for both competitive and monopolistic firms, and that of the former is always smaller than that of the latter. That is, $\frac{\alpha(1-\beta)d}{1-\alpha\beta}<w_{\mathrm{M}}^{\mathrm{lF}}<\alpha d<w_{\mathrm{M}}^{\mathrm{lh}}$. If a monopolistic firm cannot adopt the Pl policy (i.e., Proposition 4.1 (ⅰ)), they have only one advantage point in the policy change, which coincides with the second advantage point of the policy change for competitive firms. This correlation is consistent with our hypothesis. Preinstallation revenues are important for firms to maintain their market positions and price advantages. Therefore, a preinstallation policy is adopted when marginal preinstallation income is smaller. Since both firm types hope to obtain more consumers and preinstallation revenue through price reductions, the profits of the two firms do not change compared to the situation without preinstalled application in the final equilibrium. This corollary shows that competition leaves symmetric firms unable to

DOI: 10.52396/JUSTC-2022-0012
JUSTC, **2022**, 52(11): 5

make superprofits by adopting preinstalled applications.

4.3 Impact of the expert segment

This study also focuses on the reaction of expert consumers to smart device firms. This section analyses how expert consumers affect firms' policy choices and profits.

Proposition 4.3. (i) Under the F and Ph policies, β has no effect on prices, whereas under the Pl policy, the price increases in β.

(ii) Under the F and Ph policies, β has no effect on the profits of monopolistic firms, whereas under the Pl policy, the profits of monopolistic firms increase in $\beta \in \left[\frac{1}{2}, 1\right]$. When $\beta < \frac{1}{2}$, there exists $\beta^0 = \frac{(w-d)(v-c+w)+\alpha d(d+w)}{(d+w)^2}$, and prices increase in $\beta \in \left(\max(0,\ \beta^0),\ \frac{1}{2}\right)$ and decrease in $\beta \in (0, \max(0,\ \beta^0))$. β has no effect on a firm's competitive profits.

Proposition 4.3 (i) found that only under the preinstallation policy with a low removal threshold, when the number of expert consumers who can remove preinstalled applications increases, does the consumer situation worsen. This is because the size of the expert segment affects the retail prices. When firms do not bundle preinstalled applications on products, expert consumers can enjoy the best-quality products without jailbreaking. At that time, the three consumer segments did not differ. Firms bundle preinstalled applications and set high removal thresholds, which affect the demand for products of hypercritical consumers among expert consumers, but expert consumers will not choose to reverse the harm. At this time, the expert and non-expert consumers did not differ. The hypercritical consumers contain the entire hypercritical segment. Finally, the optimal price of a monopolistic firm is affected only by the market size of hypercritical consumers, α; that is, when α increases, firms' retail prices decrease. For competitive firms, all consumers use preinstalled applications, and firms return all marginal preinstallation income to consumers. Therefore, expert consumers do not affect the prices.

Proposition 4.3 (ii) explains that, for monopolistic firms under the F and Ph policies, expert consumers do not affect profits. This is because the demand and retail price are unrelated to the proportion of market segments when the F policy is adopted; when Ph is adopted, the demand and retail price are related only to the proportion of the market segment with negative utility among consumers. When firms adopt the Pl policy, expert consumers have a non-monotonic impact on profits.

Proposition 4.4 discusses how the segment size of expert consumers, β, affects the firms' policy choices.

Proposition 4.4. (i) As β increases, competitive firms prefer to bundle preinstalled applications onto devices when w is smaller.

(ii) For monopolistic firms, when α is not too large, the increase in β makes firms more likely to adopt the Pl policy when w is at the middle level, and when α is large, the increase in β causes firms to abandon the Pl policy at any level of w.

Proposition 4.4 shows that the existence of expert consumers is a crucial factor affecting whether firms adopt the Pl policy. Since $\frac{\alpha(1-\beta)d}{1-\alpha\beta}$ decreases on β, the conclusion of Proposition 4.4 (i) can be obtained directly. This is because expert consumers remove the preinstalled applications to the greatest extent possible. When the removal threshold set by firms is very low, only consumers in one segment (i.e., hypercritical nonexpert consumers) are damaged. When β increases, the number of hypercritical non-expert consumers $\alpha(1-\beta)$ decreases, and thus, the average quality damage of products is reduced. Therefore, even when marginal preinstallation income is small, the direct impact of preinstalled applications is dominant. Firms adopt the PL policy in advance.

Proposition 4.4 (ii) describes the impact of expert consumers on the monopolistic firms: as the policy change point of a monopolistic firm is complex, we compare $w = \alpha d$ (where $\pi(\mathrm{F}) = \pi(\mathrm{Ph})$). When the former is larger, the monopolistic firm adopts the PL policy when w is at the middle level. By contrast, the monopolistic firms adopt only Ph and F policies. The reason for this result is that when α is very large, the growth of β leads to a significant increase in the size of the hypercritical expert segment; thus, the indirect effect dominates the direct effect more easily. When a vast majority of consumers hate preinstalled applications and more consumers try to uninstall them, they cannot obtain more differential profits from the preinstallation revenue. At this time, firms tend not to adopt Pl. Only when the marginal preinstallation income is very high ($w > \alpha d$) will firms lose most of the hypercritical expert consumers to maximize preinstallation revenue. When α is not very large, the growth of β has a relatively mild effect on the size of the hypercritical expert segment. Similar to the analysis in Proposition 4.4 (i), the direct effect is easier to dominate at this time, so the Pl policy has room to exist when w is at the medium level.

5 Conclusions

Although preinstalled applications can create benefits for smart device manufacturers, the choice of the preinstallation mode may be affected by some commercial factors. Consumers' initiative in dealing with preinstalled applications makes them strategic actors in deciding whether to remove the applications. Our model considers the interaction between firms that provides bundled products and consumers who reverse damage from unloading behavior. Our research expands previous research on preinstalled applications in two dimensions. First, we allow for competitive firms in the market. Second, we divide consumers into three segments: tolerant consumers, hypercritical non-expert consumers, and hypercritical expert consumers.

In our model, marginal preinstallation income is an exogenous variable. Intuitively, as marginal preinstallation income increases, competitive firms tend to choose policies that force more market segments to use preinstalled applications. When firms choose to bundle the applications on the product and gradually increase the removal threshold, they will cut profits in favor of the customers in the form of price reductions. Symmetrical firms fully subsidize their pre-installation

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JUSTC, **2022**, 52(11): 5

revenues to consumers. In the context of the three possible symmetrical policies, both firms obtain the same income. In addition, preinstalled applications not only subsidize firms' increasingly diluted hardware revenues but also have strategic significance for competitive firms to obtain an advantageous position in the price war. We also compare competitive firms with monopolistic firms, showing that competition affects the firm's preinstallation application decisions. Compared to the monopolistic situation, firms in a competitive situation can always adopt the Pl policy to avoid giving other firms a price advantage.

On the one hand, the development and popularization of technology improve the commercial value of preinstalled applications. However, it greatly reduces the obstacles for consumers to obtain and disseminate information and learn to remove such applications. As preinstalled applications have negative utility and hypercritical consumers will try to remove preinstalled applications, firms will not always choose policies that can maximize preinstalled benefits. The initiative of expert consumers in reacting to firms is a key factor in our model. In fact, the proportion of expert consumers affects the direct and indirect effects of preinstalled applications, ultimately affecting a firm's policy decisions.

The theoretical contributions of this paper are as follows: First, the current literature on preinstalled applications is mostly based on its inherent characteristics and empirical research on consumer use. This study establishes an analytical model to analyze preinstalled applications from a commercial perspective and proves that binding preinstalled applications is not always beneficial to firms. Second, this study extends Ref. [7] to competitive firms and compares preinstalled application policies under monopoly and competition. Finally, our study takes into account how product modification from the consumer side, that is, the unbundling behavior of consumers to bundles, affects firms' decision-making, which supplements the literature on bundling.

The practical contribution of this study is to provide enlightenment for managers. For example, when a firm's market power is relatively small or in the face of the growth of technical consumers brought by increasingly mature root technology, the firm can choose not to bundle preinstalled applications on products. Even when the marginal preinstallation income the firm can obtain is very high, most people cannot uninstall the preinstalled applications, which may not make the firm profit to the greatest extent. Firms can consider bundling applications that reduce consumer use costs or utility damage to consumers because higher negative utility means that firms need to subsidize more preinstallation revenue to consumers in the form of price reduction.

We also observed examples of real policy changed similarly to our model results. For example, when dealing with competitors and a large number of users who denounced its preinstalled applications, Apple initially wanted full control over its ecosystem, agreed to unload some preinstalled applications in subsequent versions (iOS 10), and then permitted users to choose third-party applications as the default settings (iOS 12). To a large extent, these changes indicate that Apple actively allows users to make their own choices to cope with the crisis of a losing market position. Another example is the OnePlus, commonly referred to as a geek smartphone, which is committed to providing a high-end hardware configuration and a system closest to Android's native system. Its ads are targeted at technology enthusiasts, and its early popularity and market position are low. In this case, OnePlus has a large proportion of expert consumers; therefore, it tends to choose a preinstallation-free policy. When a firm has a strong foothold, its advantages gradually appear. Recently, it began to promote more types of users. The international OxygenOS of the OnePlus 8/8 Pro/Nord released in 2020 includes bloatware that cannot be removed.

This study also has some limitations, such as considering only the competition of symmetrical firms. Future research can extend this to firms with asymmetric competition, which may further our understanding of this phenomenon.

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Conflict of interest

The authors declared that they have no conflict of interest.

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Appendix

A.1. Proof of Lemma 4.1

First, according to the steps outlined in Section 4.1, we calculated the indifferent points, as summarized in Table A1 below.

When we plug the indifferent point into Eq. (2), we can solve the following first-order condition: $\frac{\partial \pi_{\mathrm{M}}}{\partial p_{\mathrm{M}}}=0$ and obtain the equilibrium prices. For these prices to constitute an equilibrium, the second-order condition must hold; that is, $\frac{\partial^2 \pi_{\mathrm{M}}}{\partial p_{\mathrm{M}}^2}=-\frac{1}{t}<0$, which obviously holds.

A.2. Proof of Proposition 4.1

Let $\pi_{\mathrm{M}}(\mathrm{Ph})=\pi_{\mathrm{M}}(\mathrm{F})$, $\pi_{\mathrm{M}}(\mathrm{Pl})=\pi_{\mathrm{M}}(\mathrm{F})$, and $\pi_{\mathrm{M}}(\mathrm{Ph})=\pi_{\mathrm{M}}(\mathrm{Pl})$. We obtained three sets of roots: $w^{\mathrm{hF}}=\alpha d$ or $w^{\mathrm{hF}}<0$ (abandoned).

$$w_{\mathrm{M}}^{\mathrm{lF}}=(v-c)(1-\alpha\beta)-d\alpha(1-\beta)(1+\alpha\beta)-\sqrt{\begin{pmatrix} d\alpha(2(v-c)-d\alpha(1-\beta))(1-\beta)(1-\alpha\beta)^2 \\ +((v-c)(1-\alpha\beta)-d\alpha(1-\beta)(1+\alpha\beta))^2 \end{pmatrix}} \text{ or } w_{\mathrm{M}}^{\mathrm{lF}}<0 \text{ (abandon);}$$

Table A1. Indifferent points of monopoly firm.

	F	Pl	Ph
θ^{T}	$(v-p_{\mathrm{M}})/t$	$(v-p_{\mathrm{M}})/t$	$(v-p_{\mathrm{M}})/t$
θ^{N}	$(v-p_{\mathrm{M}})/t$	$(v-p_{\mathrm{M}}-d)/t$	$(v-p_{\mathrm{M}}-d)/t$
θ^{E}	$(v-p_{\mathrm{M}})/t$	$(v-p_{\mathrm{M}})/t$	$(v-p_{\mathrm{M}}-d)/t$

DOI: 10.52396/JUSTC-2022-0012
JUSTC, **2022**, 52(11): 5

$$w_{\mathrm{M}}^{\mathrm{lh}}=\frac{1}{2-\alpha\beta}\left(c-v+d(1-\alpha+\alpha\beta)+\sqrt{\begin{matrix}(v-c)^2+2(v-c)(1+\alpha-2\alpha\beta)d\\+d^2(1-\alpha(6-\alpha-4\beta))\end{matrix}}\right)\text{ or } w_{\mathrm{M}}^{\mathrm{lF}}<0\text{ (abandon)};$$

$\pi_{\mathrm{M}}(\mathrm{Ph})<\pi_{\mathrm{M}}(\mathrm{Pl})<\pi_{\mathrm{M}}(\mathrm{F})$ can easily be examined when $w<\frac{\alpha(1-\beta)d}{1-\alpha\beta}$. In addition, $\pi_{\mathrm{M}}(\mathrm{Ph})>\pi_{\mathrm{M}}(\mathrm{Pl})>\pi_{\mathrm{M}}(\mathrm{F})$ when $w>d$.

Based on the above proof, we can draw a figure for these two cases for ease of explanation. Fig. A1a and b show cases Proposition 4.1 (i) and (ii), respectively.

A.3. Proof of Lemma 4.2 & Proposition 4.2

The flow of this proof is analogous to that of Lemma 4.1.

Solving the first-order condition $\frac{\partial\pi_j}{\partial p_j}=0$, we obtain equilibrium prices. For these prices to constitute an equilibrium, the second-order condition must hold; that is, $\frac{\partial^2\pi_j}{\partial p_j^2}=-\frac{1}{t}<0$, which obviously holds.

The nine obtained equilibria are shown in Tables 3 and A2. Based on Table A2, we obtain a simplified payoff matrix as shown in Fig. A2.

Fig. A2 a–d represent cases of $w<\frac{\alpha(1-\beta)d}{1-\alpha\beta}$, $\frac{\alpha(1-\beta)d}{1-\alpha\beta}\leqslant w<\alpha d$, $\alpha d\leqslant w<d$, and $d\leqslant w$, respectively.

"+" and "-" represent the relative size relationships of the equilibrium profits. In addition, "/" means that size has no impact on policy decisions. Q.E.D.

A.4. Proof of Proposition 4.3

Obviously, $\frac{\partial p_{\mathrm{M}}(\mathrm{Ph})}{\partial\beta}=\frac{\partial p_{\mathrm{M}}(\mathrm{F})}{\partial\beta}=0$, $\frac{\partial p_{\mathrm{M}}(\mathrm{Pl})}{\partial\beta}=\alpha w>0$; $\frac{\partial\pi_{\mathrm{M}}}{\partial\beta}>0$. In addition, $\frac{\partial\pi_{\mathrm{M}}(\mathrm{F})}{\partial\beta}=\frac{\partial\pi_{\mathrm{M}}(\mathrm{Ph})}{\partial\beta}$ and $4t\frac{\partial\pi_{\mathrm{M}}}{\partial\beta}=2\alpha(d-w)(v-c-d\alpha(1-\beta)+w(1-\alpha\beta))-4dw\alpha^2(1-2\beta)$. It is evident that $\frac{\partial\pi_{\mathrm{M}}}{\partial\beta}>0$ if $\beta>\frac{1}{2}$. Then, by solving $\frac{\partial\pi_{\mathrm{M}}}{\partial\beta}=0$, we

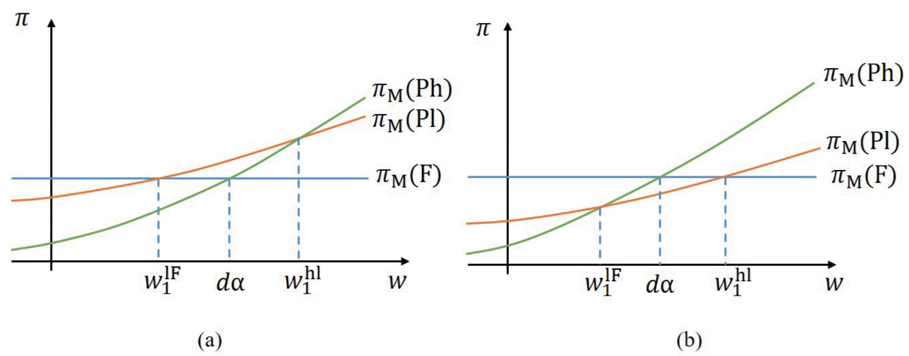

Fig. A1. Profit functions of Proposition 4.1.

Table A2. Equilibrium profit of competitive firm.

	F	Pl	Ph
F	$\frac{t}{2},\frac{t}{2}$	$\frac{(3t+d\alpha(1-\beta)-(1-\alpha\beta)w)^2}{18t}$, $\frac{\left(\begin{matrix}(3t-d\alpha(1-\beta)+(1-\alpha\beta)w)^2-\\9wd\alpha^2\beta(1-\beta)\end{matrix}\right)}{18t}$	$\frac{(3t-d\alpha-w)^2}{18t}$, $\frac{(3t+d\alpha+w)^2}{18t}$
Pl	$\frac{\left(\begin{matrix}(3t-d\alpha(1-\beta)+w(1-\alpha\beta))^2-\\9wd\alpha^2\beta(1-\beta)\end{matrix}\right)}{18t}$, $\frac{(3t+d\alpha(1-\beta)-w(1-\alpha\beta))^2}{18t}$	$\frac{t}{2},\frac{t}{2}$	$\frac{\left(\begin{matrix}(3t-(w-d)\alpha\beta)^2-\\9wd\alpha\beta(1-\alpha\beta)\end{matrix}\right)}{18t}$, $\frac{(3t+(w-d)\alpha\beta)^2}{18t}$
Ph	$\frac{(3t-d\alpha+w)^2}{18t}$, $\frac{(3t+d\alpha-w)^2}{18t}$	$\frac{(3t+(w-d)\alpha\beta)^2}{18t}$, $\frac{\left(\begin{matrix}(3t-(w-d)\alpha\beta)^2-\\9wd\alpha\beta(1-\alpha\beta)\end{matrix}\right)}{18t}$	$\frac{t}{2},\frac{t}{2}$

DOI: 10.52396/JUSTC-2022-0012
JUSTC, **2022**, 52(11): 5

(a)

Firm A \ Firm B	F	Pl	Ph
F	(0, 0)	(+, -)	(+, -)
Pl	(-, +)	(0, 0)	(/, 0)
Ph	(-, +)	(-, /)	(0, 0)

(b)

Firm A \ Firm B	F	Pl	Ph
F	(0, 0)	(-, /)	(+, -)
Pl	(/, -)	(0, 0)	(/, 0)
Ph	(-, +)	(-, /)	(0, 0)

(c)

Firm A \ Firm B	F	Pl	Ph
F	(0, 0)	(-, /)	(-, +)
Pl	(/, -)	(0, 0)	(-, -)
Ph	(+, -)	(-, -)	(0, 0)

(d)

Firm A \ Firm B	F	Pl	Ph
F	(0, 0)	(-, /)	(-, +)
Pl	(/, -)	(0, 0)	(-, +)
Ph	(+, -)	(+, -)	(0, 0)

Fig. A2. Payoff matrix of competitive firms.

obtain $\beta=\beta^0=\dfrac{(w-d)(v-c+w)+\alpha d(d+w)}{\alpha(d+w)^2}$. Therefore, $\dfrac{\partial\pi_M}{\partial\beta}>0$ in $\beta\in\left(\max\{0,\ \beta^0\},\ \dfrac{1}{2}\right)$ and $\dfrac{\partial\pi_M}{\partial\beta}<0$ in $\beta\in(0,\max\{0,\ \beta^0\})$. Q.E.D.

A.5. Proof of Proposition 4.4

(i) Obviously, $\dfrac{\alpha(1-\beta)d}{1-\alpha\beta}$ increases in β. To prove (ii), we compared $\pi(\mathrm{Pl}),\pi(\mathrm{F})$ with $w=d\alpha$. As Fig. 2 shows, $\pi(\mathrm{Pl})>(<)\pi(\mathrm{F})$ is the equivalent condition to $w_M{}^{\mathrm{lF}}<(>)w_M{}^{\mathrm{lh}}$. Therefore, when $w=d\alpha$, if $\pi(\mathrm{Pl})$ increases, monopolistic firms are more likely to adopt the Pl policy. Plug $w=d\alpha$ into $\dfrac{(w-d)(v-c+w)+\alpha d(d+w)}{\alpha(d+w)^2}$, and obtain $\dfrac{-(1-\alpha)(v-c+\alpha d)}{\alpha d(1+\alpha)^2}+\dfrac{d}{1+\alpha}$ because $v-c\gg 1$, only α is sufficiently large that $\beta^0|_{w=d\alpha}>0$. Q.E.D.

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JUSTC, **2022**, 52(11): 5