The Achilles tendon of dynamic pricing —The effect of Consumers' Fairness Preferences on Platform Dynamic Pricing Strategies

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In this paper, we study the effect of consumers' fairness preferences on dynamic pricing strategies adopted by platforms in a non-cooperative game. Our study reveals that, in a one-shot game, if consumers have fairness preferences, dynamic prices will slightly decline. In a repeated game, dynamic prices will be reduced even when consumers do not have fairness preferences. When fairness preferences and repeated game are considered simultaneously, dynamic prices are most likely to be set at fair prices. We also discuss the effect of platforms' discounting factors, the consumers' income and alternative choices of consumption on the dynamic prices. Our findings illustrate the importance of incorporating behavioral elements in understanding and designing the dynamic pricing strategies for platforms and the implications on social welfare in general.
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I. Introduction

To match supply and demand more efficiently, platforms often apply dynamic pricing strategies. We have witnessed a few high-profile cases in recent years, for example, the "surge pricing" by Uber and the price discrimination controversies by Amazon in 2000. With the support of the Internet and big data technologies, platforms are able to obtain a rich set of consumer information, including their consuming habits, spending capabilities, the urgency of the trading needs, etc. Together with detailed supplier information, platforms can then simulate real-time transaction scenarios to implement "dynamic pricing" individually for each deal. Efficient market theory justifies the dynamic pricing strategies as they serve to efficiently balance the supply and demand on a real-time basis. Indeed, studies on Uber suggest dynamic pricing can reduce demand by pricing out the low wiliness to pay (WTP) consumers, so that the limited supply could be allocated to high-valued demand. Besides, it induces suppliers to increase supply with a higher reward, which is especially relevant in platform economies, where the elasticity of

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supply is relatively high. The overall results of dynamic pricing apparently are overwhelmingly positive (Cohen et al., 2016; Castillo et al., 2017). On the other hand, many consumers complain about dynamic pricing as "price gouging" by platforms, because prices are often increased when the service is in urgent need (as in the case of Uber). In addition to the improper kick-in time of surging prices (mostly when demand is inelastic), uncertainty and process opacity (Hinz et al., 2011; Chen et al., 2015) all result in dynamic pricing having an impression of "fishing in troubled waters". Dynamic pricing based on consumer characteristics(i.e., price discrimination) is often conducted without the consumer's consent and awareness (as in the case of Amazon). They were shown to lead to greater consumer dissatisfaction than time-based dynamic pricing (Haws and Bearden, 2006). More problematically, they could lead to public outcry if later exposed to the public or even come into conflict with laws and regulations of the local jurisdiction. Anecdotal evidences suggest dynamic pricing had resulted in a distasteful reputation of the platforms and rampant complaint from both consumers and suppliers [1]

As a result, despite the potential efficiency gain of dynamic pricing based on economic theory, platforms often stumble over this strategy and are increasingly unwilling to associate their business practices with, even the name of, this strategy[2]. Therefore, there is an urgent need, from both the economic and business field, to fully examine the pros and cons of dynamic pricing, explain why this strategy works in theory but fails in practice, and propose remedies for its implementation by platforms.

In this article, we build on the notion that consumers' utility involves both the consumption effectiveness, i.e., the utility derived from consumption itself, and the transaction effectiveness, a key component of which is the perception of fairness (Thaler, 1985). For high-frequency consumption like travel expenses, dynamic pricing usually kicks in when demands are high and urgent. Hence, it is easy to trigger consumers' fairness preferences. Further, we argue that no matter the dynamic pricing takes the form of surge pricing to meet high demand, or price discrimination based on consumer characteristics, if consumers believe that the dynamic price is higher than the fair price (in this article, fair price is defined as the sum of cost plus half of consumer surplus, as per Nash bargaining, see Charness and Rabin, 2002), consumers' fairness preferences of the price hikes will be triggered, prompting consumers to retaliate against the platform's "hostile"

[1]See Gurley, B. "A Deeper Look at Uber's Dynamic Pricing Model." *Above the Crowd*, 11 Mar. 2014, abovethecrowd.com/2014/03/11/a-deeper-look-at-ubers-dynamic-pricing-model/. LiuLiu. "What Is the Reason for DiDi's Existence as a Rogue Enterprise?" Sina Blog, 21 June 2017, blog.sina.com.cn/s/blog_65be90b90102wt5t.html. And Dholakia, Brown, R. G. "Uber's Surge Pricing: 4 Reasons Why Everyone Hates It." *Government Technology: State & Local Government News Articles*, Emergency Management, 27 Jan.2016,www.govtech.com/applications/Ubers-Surge-Pricing-4-Reasons-Why-Everyone-Hates-It.html

[2]For example, a commentary on Harvard Business Review suggests that business managers use a different name, rather than dynamic pricing, for the strategy. See https://hbr.org/2015/12/everyone-hates-ubers-surge-pricing-heres-how-to-fix-it

(unfair) behaviors. Moreover, if the platform and consumers are in a long-term repeated game, one specific trading of a transaction will not only determine the consumer's current cooperative or non-cooperative interaction with the platform, but also affect subsequent transactions with the same platform. Therefore, the fairness preferences of consumers will ultimately affect the long-term development of the platform.

We first derive a general utility function of the consumer based on services/goods provided by a specific platform and his or her other consumption choices, and then introduce the fairness preference into the previous utility function as the basis for subsequent analyses. Next, under a dynamic game with complete information, we analyze the interaction between consumers and platforms, in which the platform formulates dynamic pricing strategies to maximize its profit, taking into account consumer's private information sets (including the fairness preference). We assume consumers' utility contains both consumption effectiveness and transaction effectiveness, and they may choose "consume" or "not consume/ choose alternative goods/services" in response to the prices and services offered by the platform. Then, based on whether to take fairness preferences into account, consumers with fairness preferences will adopt "tit for tat" or "trigger" strategies to retaliate against perceived unfair dynamic pricing. Taking into account the differences between repeated game and one-shot game, we derive the equilibrium strategies for platform companies and consumers in four different scenarios and their corresponding equilibrium prices.

Our research reveals both fairness preference and repeated game have an impact on dynamic pricing. In a one-shot game, if consumers have fairness preference, dynamic prices in equilibrium will slightly decline, compared to consumers without fairness preference. On the other hand, in a repeated game with consumer fairness preferences, prices are most likely to be reduced to the fair price. Lastly, we find that consumer's weaker retaliation and higher income, as well as higher switching cost, are all associated with higher equilibrium dynamic prices[3].

Our research provides a basic theoretical benchmark for the study of the combination of fair game, repeated game and platform economics. In the digital economy era, consumers' fairness perception is an important dimension for the platform managers to consider in determining the dynamic pricing strategy. If platform companies do not take fairness preferences of consumers or long-term cooperation into account in its pricing decisions, it will likely lead to consumer dissatisfaction and retaliation, which would damage the platform's long-term profits. Therefore, when consumers place great emphasis on fairness, or companies attach great importance to future profits, a fair distribution of consumer surplus between the enterprises and consumers can be a determining factor to the sustainable development of the platform. The findings also suggest that, in this digital economy era where it's increasingly difficult for consumers to hide private infor-

[3]They will exceed the fair prices, but still are less than the prices under first-degree price discrimination, and the specific value depends on the size of the parameters.

mation from platforms, a stronger awareness of fairness, combined with credible retaliation strategies could be the best instruments for consumers to safeguard their rights and interests. Finally, from a social planner's perspective, it is important to improve the interaction mechanism between consumers and enterprises, to ensure that consumers could reward or retaliate effectively against platform companies' strategies based on fairness preferences, thus forming a benign feedback mechanism.

The paper makes contribution on several important grounds. Firstly, we propose a game theory model, by incorporating the fairness perception, to reconcile the puzzle of dynamic pricing: namely its efficient performance in theory but uncomfortable taboo-like status in practice. Secondly, the findings, from a consumer-platform perspective, supplement the literature on price discrimination, especially with respect to its effect on consumer's level of satisfaction (Major, 1994; Major and Testa, 1989) and the consumer-supplier relationship (Garbarion, 2003; Choi and Mattila, 2009; Anderson and Simester, 2009). While the literature focuses on a perception of price stickiness by the consumers, this paper introduces the fairness perception as a different channel. Thirdly, by comparing the one-shot game with repeated games, the paper also contributes to the analysis of repeated game concerning the relationship of platforms and consumers. The existing studies generally focus on platform strategies in the early period to establish business goodwill (Tirole, 1996) and enhance consumer brand loyalty (Yang, 2008). Our study provides an important angle of how consumer's fairness perception can affect the relationship in a repeated game. Lastly, our findings contribute timely to the policy discussion on platform regulation. For example, a credible retaliation strategy of the consumer depends on the availability of other goods/services, which calls for regulator's intervention to foster platform competition.

II. Background and Research Development

There are two forms of dynamic pricing: the first is to charge differently in accordance with dynamic changes of supply and demand that affect the partial equilibrium (Kimes, 2000; Robinson and Lakhani, 1975). The prices depend on dynamic factors influencing supply and demand, such as limited production supply capacity (Biller et al., 2002), fluctuations in costs of raw material, labor (Robinson and Lakhani, 1975), uncertain market demand, as well as production timeliness (Gallego and van Ryzin, 1994). In platform economies, the "surge pricing" strategy of Uber is associated with matching the "supply and demand", which fits the first definition of dynamic pricing.

The second is to charge differently based on the characteristics of targeted consumer groups/individuals (Yelkur and Neveda DaCosta, 2001). In this case, platforms utilize available consumer information, e.g., the historical purchase records, to estimate the willingness to pay, and charge accordingly. This dynamic pricing strategy is, in essence, price discrimination (Taylor, 2002). Historically, this form of dynamic pricing mainly aimed at customer groups, thus it belongs to third-degree price discrimination. For instance, e-commerce platforms adopt dynamic pricing strategies according to the characteristics of consumer groups (Gupta et al., 2000; Oh and Lucas, 2006); or airlines identify consumer identities and key purchasing elements to determine their current purchasing psychology, and then design multi-tariff pricing models to customers; or DiDi Corporation (a Chinese ride-hailing platform company) divides Beijing into more than seventy regions to plate differential pricing. With digital technologies, third-degree price discrimination can evolve into "personal-based pricing", i.e., the first-degree price discrimination. Again, take Uber as an example, there has been instances of charging different people at different prices for the similar services (Chen et al., 2015). For example, the Uber platform states that

"...the algorithm calculates the shortage of transport capacity through the real-time ratio of demand/supply within the user's area; and then combines other characters to determine the probability of the order's sale. If the order's transaction probability is too low, suggested prices will be calculated based on historical data and current conditions."

Matthew Dunn (Uber staff) also points out that Uber uses machine learning algorithms to predict consumer characteristics, such as the income status, willingness to pay, etc., based on which individual-level price discrimination can be applied (Newcomer, 2017).

Hence, it can be deduced that a platform's dynamic pricing pattern is different from the traditional pattern. Dynamic pricing, traditionally, is mainly determined by supply and demand variations at different times. Now platforms can conduct sophisticated real-time based dynamic pricing and "personal-based" price discrimination by using the advanced digital technologies.

Efficient market theory suggests that dynamic pricing should be efficiency-improving, by matching supply and demand on a real-time basis. Supply response on platform can be much faster compared to supply of traditional goods, thus improve the signaling effect of prices. Consumers, on the other hand, are independent decision-makers and able to make rational analysis about the dynamic prices to make optimal decisions. Based on this argument, a large body of literature on dynamic pricing aims to detect their regulatory effects. Hall et al. (2015) and Kaylene (2016) show that surging price are statistically consistent with reduced expected waiting time, increased supply and decreased demand. Castillo et al. (2017) proposes that, when the demand exceeds supply, the conventional pricing of online ride-hailing platforms will force limited drivers to take long-distance orders, reducing effective working hours and wasting resources, leading to low efficiency (wild goose chases). In their paper, the authors prove that the net effects of dynamic pricing on consumer surplus, driver surplus and social welfare are all positive.

Empirical studies on dynamic pricing, much of which focus on Uber, reach more mixed results. Cohen et al. (2016) suggests Uber generates a large total consumer surplus, equivalent to six times the company's commission and two times the driver's income by analyzing the Uber dynamic pricing data. Castillo et al. (2017) also find evidence of lowing "wild goose chase" with Uber data, albeit mitigated to certain extent by the application of surge pricing. On the other hand, Diakopoulos (2015) reaches an opposite conclusion, claiming that, after analyzing the official Uber data, the dynamic pricing disrupts the geographical distribution of existing drivers, leading to persistent regional mismatches in supply and demand. Besides, Chen et al. (2015) pointed out that Uber is a black-box by using surge pricing algorithm and raise important questions about fairness and transparency.

However, the existing studies mainly focus on one-shot game between companies and consumers, or the regulating effects on market equilibrium, without considering the impact of price discrimination on the relationship of parties involved, such as the loss of the transactions' effectiveness induced by increased price, and its effect on the long-term interaction. Building on studies in behavioral economics on consumption effectiveness and transaction effectiveness as different components of consumer's utility, and price fairness as a key component of transaction effectiveness (Thaler, 1985), we apply fairness perception as the mediating variable between the decisions of consumers and companies. We investigate the impact of consumers' fairness preferences on the company's pricing strategy and the final surplus distribution. Many studies point out price discrimination will trigger consumers' perception of fairness, thus affecting consumer's level of satisfaction (Kaufmann et al. 1991; Kimes 1994; Urbany et al. 1989). We find evidences from the literature to support our reasoning. Existing empirical studies on ride-hailing often find that consumer demand is inelastic (Cohen et al., 2016), which, to some extent, reflects the urgency of demand during price surging. However, according to Kahneman et al. (1986), consumers find it difficult to accept rising prices except for costs-induced, while increasing prices when demand is tight will intensify consumers' dissatisfaction. The findings by Chowdhry (2016) that Uber charges higher prices to consumers with low battery phones certainly push the dissatisfaction further.

Our framework of analysis builds on the literature of fair game and social preference. Rabin (1993) first introduced fairness preferences into the game theory, emphasizing that people have both self-interest preferences and fair and reciprocal preferences. Hence, individual behaviors depend on the perception of others' motivations. He applied a "kindness function" to identify the behavioral motives, claiming people intend to "reciprocate" or "retaliate" against others, even at the expense of their own material interests. On the basis of Rabin (1993), Falk and Fischbacher (2001), Charness and Rabin (2002) further extend the fair game to incorporate income distribution of the players. They show that people's judgement of the others' behaviors depends on the outcomes of their income distribution. The resulting fair income distribution from several experimental games suggests that people have a social preference for an equal utility distribution. Bolton and Ockenfels (2000) also find that people will compare others' income with themselves in a transaction, and a roughly equal distribution will be viewed as fair allocation. Based on their research, Xia et al. (2004) emphasize that both the cognitions of companies' unfairness preferences and unfair outcomes of pricing strategies will trigger consumers' fairness preferences. However, the existing studies on this topic concentrate on incentive contracts and principle-agent issues in the labor market (Wang, et al., 2013), while paying little attention to the quantitative research of product market. In this article, the measurement of "fairness" incorporates the above-mentioned concepts. The consumers' fair perception of the platform's pricing motives depends on if a fair distribution of the consumer surplus is achieved. Similarly, consumers' fairness perception refers to the cognition of companies' motives, relying on whether dynamic pricing promotes a fair outcome. For example, if the dynamic price is higher than the fair price, it will be viewed as a signal of the company's non-good intention, which could trigger consumer's retaliation. Many studies have shown that, after feeling offended by unfair prices, consumers will develop emotional reactions such as anger, depression, and extremism (Finkel, 2001, p. 57), which, in turn, results in their retaliatory behaviors, such as ending trading relationships, spreading negative information, or other retaliatory behaviors against corresponding manufacturers (Campbell, 1999). Depending on whether to take fairness into account, and the difference between a one-shot game and repeated game, we obtain equilibrium strategies and equilibrium pricing for platform companies and consumers under the four different scenarios, and analyze the impact of fairness and long-term repeated game on dynamic pricing.

III. Model Setup

Consider a situation where a platform, abbreviated as platform in the following text of the section, has complete knowledge of consumers' preferences and constraints, and it formulates profits-maximizing dynamic prices according to this information set to charge individual-based prices. We assume that the utility of a consumer includes consumption effectiveness and transaction effectiveness (fairness preferences). Each consumer chooses to "consume" or "not consume" to maximize his total utility given the price provided by the platform. If the price exceeds the maximum that he can tolerate, he may turn to consume alternative goods/services, even if their consumption effectiveness may decrease. If the price exceeds the fair price but is within the maximum threshold, the consumer will accept the offer, and the transaction will continue, but the consumer may take certain retaliatory measures *ex post*. If the transaction goes through, the platform's income equals its price; otherwise, the platform's income is zero. Since the marginal cost of a single transaction has little effect on the platform's total cost, we set the marginal cost to zero in this model. Thus, the problem of maximizing profit for the platform is equivalent to the problem of maximizing revenue.

First, we derive a general utility function based on a service provided by one platform and its substitute goods provided by its competitors, and the consumer's other product options. Then we introduce fairness preferences to derive a specific utility function as the basis for subsequent analysis. Next, we apply a non-cooperative game framework to analyze the interaction between the consumer and the platform, in which the platform formulates profit-maximizing dynamic prices according to the consumer's private information set. The consumer chooses to "consume" from the platform or not. This is a dynamic game with complete information. Then, based on whether to take fairness factors into account or not, and whether to incorporate a repeated game or not, we obtain equilibrium strategies and equilibrium pricing for the consumer and the platform in four different situations.

A. *General utility function without fairness preferences*

First, we derive the general utility function without fairness consideration.

Let's assume that the consumer, with the budget constraint I, chooses goods /services set (X, Y, Z), including what is provided by the platform, denoted by X, whose price is p_x, alternative goods/services, denoted by Y, whose price is p_y, and other necessary consumptions Z, whose price is p_z under Note that we assume $(X, Y) = (1, 0)$ or $(0, 1)$. X, Y belong to the consumer staples, and the consumer has to choose one of the two to maximize his utility u:

$$Max\ u = u(X, Y, Z)$$

$$s.t.\ p_x X + p_y Y + p_z Z \leq I$$

(1) Suppose the consumer chooses X, which is provided by the platform, then we have:

$$\begin{cases} Max\ u = u(1, 0, Z) \\ s.t.\ p_x + p_z Z \leq I \end{cases}$$

In this case, the utility of the consumer is then a function of I and p_x:

$$u = V_x(I - p_x)$$

(2)Suppose the consumer chooses alternative consumer goods/services Y, then:

$$\begin{cases} Max\ u = u(0, 1, Z) \\ s.t.\ p_y + p_z Z \leq I \end{cases}$$

In this case, the utility of the consumer is then a function of I and p_y:

$$u = V_y(I - p_y)$$

Assume V_x and V_y are continuous and derivative, p_x, $p_y \ll I$, then with Lagrange

Mean Value Theorem we have:

$$\frac{V_x(I-p_x)-V_x(I)}{-p_x} = V_x'(I-\theta p_x) \approx V_x'(I)\ ,\ \theta \in (0,1)$$

We get:

$$V_x(I-p_x) = V_x(I) - V_x'(I)p_x$$

Equivalently,

$$V_y(I-p_y) = V_y(I) - V_y'(I)p_y$$

To simplify the notation, let m_x be the utility generated from consuming X, m_y be the utility generated from consuming Y, and k_I be the marginal utility of income of the consumer, which usually decreases with income I. Then we get the net utility of consuming X or Y respectively:

$$V_x(I-p_x) = m_x - k_I p_x$$

$$V_y(I-p_y) = m_y - k_I p_y$$

That is, the net utility of consuming what the platform provides is related to the consumer's consumption satisfaction, income and the price offered by the platform.

B. Utility function with fairness preferences

Next, we apply Rabin's kindness function to define the utility function that includes fairness preferences:

Definition 1: If player i believes player j is choosing strategy b_j, the kindness player i is giving to player j by choosing strategy a_i is given by:

$$(1)\ \ f_i(a_i,b_j) = \frac{\pi_j(b_j,a_i)-\pi_j^e(b_j)}{\pi_j^h(b_j)-\pi_j^{min}(b_j)}\ if\ \pi_j^h(b_j) \neq \pi_j^{min}(b_j),\ otherwise\ f_i(a_i,b_j)=0$$

In formula (1), $\pi_j(b_j,a_i)$ represents player j's payoff brought by player i choosing strategy a_i, $\pi_j^h(b_j)$ represents player j's highest possible payoff, $\pi_j^{min}(b_j)$ represents player j's lowest possible payoff. $\pi_j^e(b_j) = \frac{\pi_j^h(b_j)+\pi_j^{min}(b_j)}{2}$ and it represents the "equitable payoff", a general reference point against which to measure how generous player i is being to player j. If $f_i(a_i,b_j)<0$, player i is giving j less than his equitable payoff, this shows player i's unkindness to player j. On the contrary, $f_i(a_i,b_j)>0$ means player i is giving j more than his equitable payoff, meaning player i is kind to player j. $f_i(a_i,b_j)=0$ describes the neutral point where player i gives j his equitable payoff.

Definition 2: Player i's belief about how kind player j is being to him is

defined as:
(2)

$$f_j^i(b_j,c_i) = \frac{\pi_i(c_i,b_j) - \pi_i^e(c_i)}{\pi_i^h(c_i) - \pi_i^{min}(c_i)}\ if\ \pi_i^h(c_i) - \pi_i^{min}(c_i) \neq 0,\ otherwise\ f_j^i(b_j,c_i) = 0$$

Note that definition 1 and definition 2 are notationally different, but their functions are formally equivalent, and their value must lie in the interval$[-\frac{1}{2}, \frac{1}{2}]$.

Let the fairness coefficient r represent players' preference for fairness and $r \in [0, \infty)$. $r > 0$ shows players value both material utility and fairness, which means they are equipped with fairness preferences and will act according to their belief about "how kind the other player is being to him." The lager r is, the bigger the weight for player i's kindness function will be in his utility function.

SO, player i's expected utility incorporating both his material utility and the players' shared notion of fairness is:

$$U_i(a_i,b_j,c_i) = \pi_i(a_i,b_j) + rf_j^i(b_j,c_i)[1 + f_i(a_i,b_j)] \tag{3}$$

Equation (3) displays the fact there is a trade-off between a player's fairness preference and material utility. If player i believes player j is treating him kindly ($f_j^i(b_j,c_i) > 0$), then i will treat j kindly by choosing an action a_i , such that $f_i(a_i,b_j)$ is positive. If, on the other hand, player j is treating player i badly as perceived by play i, then $f_j^i(b_j,c_i)$ will be negative, and player i will choose a negative $f_i(a_i,b_j)$.

To apply the specific utility function to our simulation, we denote the consumer as player 1, the platform as player 2, and the consumer chooses a strategy $a_1 \in \{(X,Y)|(X,Y) = (1,0)\ or\ (0,1)\}$, and the platform's strategy is denoted as $b_2 \in \{p_x|p_x > 0\}$, the consumer believes that the platform believes his strategy to be $c_1 \in \{(X,Y)|(X,Y) = (1,0)\ or\ (0,1)\}$.

Given p_x, the fairness utility of the consumer is:

$$\begin{aligned} U_1((1,0),p_x,(1,0)) &= \pi_1((1,0),p_x) + rf_2^1(p_x,(1,0))[1 + f_1((1,0),p_x)] \\ &= m_x - k_Ip_x + \frac{3}{2}r(\frac{1}{2} - \frac{p_x}{p_y + \frac{m_x - m_y}{k_I}}) \end{aligned} \tag{4}$$

The first half of Equation (4), $m_x - k_Ip_x$, represents consumption effectiveness, which is decided by consumption effectiveness coefficient m_x and surging price p_x. In addition, when the income is higher, the impact of price surging on the total utility will be smaller. And the latter part of equation (4), $\frac{3}{2}r(\frac{1}{2} - \frac{p_x}{p_y + \frac{m_x - m_y}{k_I}})$ represents the consumer's transaction effectiveness, which is generated from his perceived kindness of the platform, and it is determined by the surging price of the platform, the price of alternative goods/services, the consumption effectiveness gap $m_x - m_y$, and the income. Specifically, a lower platform surging price p_x, higher price of alternatives p_y, greater consumption effectiveness gap $m_x - m_y$, higher income, and larger perceived kindness all lead to higher utility U_1. Note that the fairness coefficient r measures the impact of the believed kindness on the transaction effectiveness, and greater fairness coefficient r contributes to greater total utility.

Similarly, when the consumer chooses alternative goods/ services, then we have $c_1 : (X,Y) = (0,1)$. The utility of the consumer is:

$$\begin{aligned} U_1((0,1), p_x, (0,1)) &= m_y - k_I m_y + r * 0 \\ &= m_y - k_I p_y \end{aligned} \tag{5}$$

Formula (5) reveals positive impact of the consumption effectiveness m_y and negative impact of the price p_y of choosing "alternative goods/ services" on its total utility, and the margin decreases with higher income.

IV. One-Shot Game Between the Consumer and the Platform

A. *Complete information dynamic game with no fairness preferences*

In a complete information dynamic game where the consumer does not value fairness, the platform formulates its profit-maximized dynamic prices. Then, the consumer chooses to consume, i.e. $(X,Y) = (1,0)$; or not consume, i.e. $(X,Y) = (0,1)$, to maximize his total utility given the price provided by the platform.

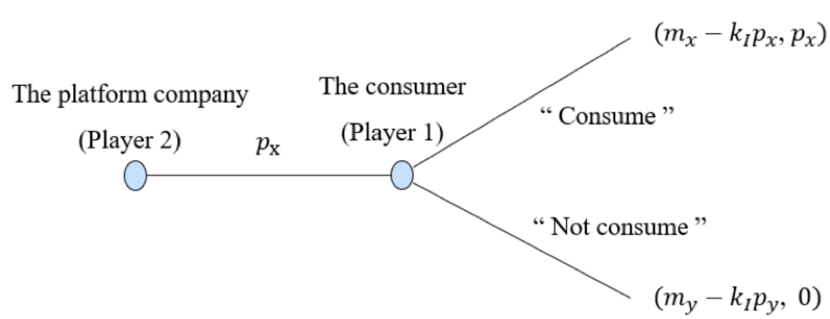

Figure 1. Sequence of Actions with no fairness preferences

Player 1 maximizes his own utility by choosing (X,Y) , given the surging price provided by player 2 p_x. If the utility of 'consume' is greater than 'not consume', the choice would be:

$$m_x - k_I p_x > m_y - k_I p_y$$

$$p_x < p_y + \frac{m_x - m_y}{k_I}$$

In this case, the platform would set p_1 to the neutral point, that is, $p_1 = p_y + \frac{m_x - m_y}{k_I}$.

On the contrary, if the utility of "consume" is less than "not consume," player 1 would turn to "alternative goods/services." The platform's income then equals to 0.

Generally, as choosing to "consume" the goods/services provided by the platform would be more convenient than "not consume/choose alternative goods /services", we assume that $m_x > m_y$, and we can get the Nash equilibrium solution:

$$p_x = p_y + \frac{m_x - m_y}{k_I} \tag{6}$$

Recall that $X = D_x(p_x) = \begin{cases} 1, & p_x < p_y + \frac{m_x - m_y}{k_I} \\ 0, & p_x \geq p_y + \frac{m_x - m_y}{k_I} \end{cases}$ is player 1's demand function for X, and we can get the consumer surplus as follows:

- When $0 < p_x < p_y + \frac{m_x - m_y}{k_I}$, the consumer surplus equals to $p_y + \frac{m_x - m_y}{k_I} - p_x$;
- When $p_x = p_y + \frac{m_x - m_y}{k_I}$, the consumer surplus is 0;
- When $p_x = 0$, the consumer surplus equals to $p_y + \frac{m_x - m_y}{k_I}$;
- When $p_x = p_y + \frac{m_x - m_y}{k_I}$, it reflects that the platform is implementing first-degree price discrimination strategy, and obtains all the consumer surplus.

In a complete information dynamic game not incorporating fairness preferences, the platform choose to set prices to the highest cost of choosing alternative goods/services and obtain all the consumer surplus.

B. Complete information dynamic game considering fairness preferences

When the consumer cares about fairness, the platform first formulates profits-maximizing dynamic prices based on the consumer's fairness preferences. The consumer chooses to consume, i.e. $(X, Y) = (1, 0)$ or not consume, i.e. $(X, Y) = (0, 1)$, to maximize the total utility given the price provided by the platform. Using (4) and (5), we get:

Based on the consumer's choice, the platform sets its profit-maximizing price as follows:

$$m_x - k_I p_x + \frac{3}{2} r \left(\frac{1}{2} - \frac{p_x}{p_y + \frac{m_x - m_y}{k_I}}\right) > m_y - k_I p_y$$

This leads to:

$$p_x < \left(\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}}\right)\left(p_y + \frac{m_x - m_y}{k_I}\right)$$

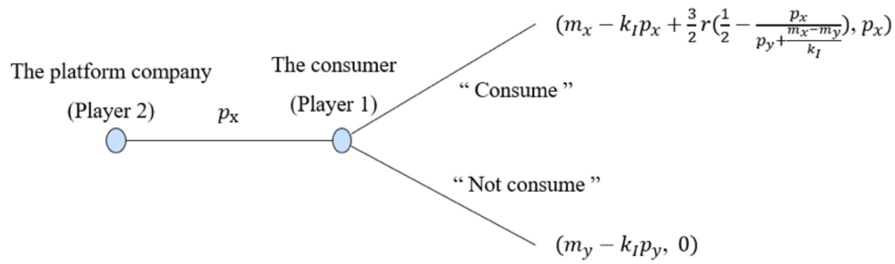

Figure 2. Sequence of Actions considering fairness preferences

When $p_x < (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$, the utility of "consume" will always be higher than the utility of "not consume", thus the platform sets p_x to this critical value.

When $f_2^1(p_x, (1,0)) > 0$, that is $\frac{3}{2}r(\frac{1}{2} - \frac{p_x}{p_y + \frac{m_x - m_y}{k_I}}) > 0$, and we get $p_x < \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$.

If the platform with information superiority prices at $\frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ and obtains half of the consumer surplus, the outcome will be regarded as fair by the consumer. Therefore, a price lower than $\frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ will be regarded as kindness; on the other hand, $p_x > \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ will be perceived as unkind behaviors. In this case, if $p_x < (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$ is satisfied, the consumer will still choose to "consume", but to take into account the fairness utility, the consumer will take retaliatory measures against the platform (which will be discussed in detail in the 'repeated game' section). If $p_x > (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$, the consumer will choose not to consume.

To summarize, after incorporating the fairness preference, if it is a one-shot game, the consumer's retaliatory measures shall have no impact on the platform. But, to ensure a transaction, the platform still need to keep prices down. The equilibrium price is:

$$p_x = (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I}) \tag{7}$$

Theorem 1: When consider consumers' fairness preference, the greater consumers' fairness coefficient (the degree of fairness preference) is, the lower the platform's equilibrium price will set.

Therefore, the platform tends to price between fair price (half of the cost of "alternative goods/services") and maximum price (equivalent to the cost of "alternative goods/services"). The specific value depends on the fairness coefficient r. The greater attention the consumer pays to fairness, the more violent her utility will change when given unfair prices, the lower price she will get.

The influence of Income (I) on platform's pricing decision is categorized by consumer's fairness coefficient (r) and the cost of alternative choice ($m_x - m_y$). When $r < \frac{2}{3}(m_x - m_y)$, the smaller the k_I is or the larger the I is, the lower the high price and the higher the fair price will be. When $\frac{2}{3}(m_x - m_y) < r < \frac{4}{3}(m_x - m_y)$, the smaller the k_I is or the larger the I is, the lower the high price and the higher the fair price will be. When $r > \frac{4}{3}(m_x - m_y)$, the smaller the k_I is or the larger the I is, the higher the equilibrium high price and fair price will be.

C. *Comparing one-shot game based on whether to incorporate fairness preferences*

Combining (6) and (7), we have:

$p_x = p_y + \frac{m_x - m_y}{k_I}$	The first degree of price discrimination, when the consumer doesn't have fairness preferences
$p_x = (\frac{1}{2} + \frac{1}{2+\frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$	The upper price limit when the consumer has fairness preferences
$p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$	The fair price.
$p_x = 0$	The price of perfect competition when the platform don' t have information superiority

Therefore, the platform tends to set a high price to obtain information rent and obtain more consumer surplus. When the consumer has fairness preferences ($r > 0$), $p_x = (\frac{1}{2} + \frac{1}{2+\frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I}) \in (\frac{1}{2}(p_y + \frac{m_x - m_y}{k_I}), p_y + \frac{m_x - m_y}{k_I})$, the platform will set a price higher than fair price but lower than the price where it obtains the entire surplus. Note that $r = 0$ leads to $p_X = p_y + \frac{m_x - m_y}{k_I}$), consistent with the outcome not incorporating fairness preferences; and $r \to +\infty$ results in $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, indicating that, when the fairness coefficient is infinite, the price will be set at the fair price. So, we have the following figure 3:

V. Repeated game Between the Consumer and the Platform

A. *Repeated game without incorporating fairness preferences*

In a repeated game, the consumer still makes decisions based on the platform's current pricing in each stage. Based on the analysis in the one-shot game without considering fairness preferences, we learned that if the dynamic price p_x is less

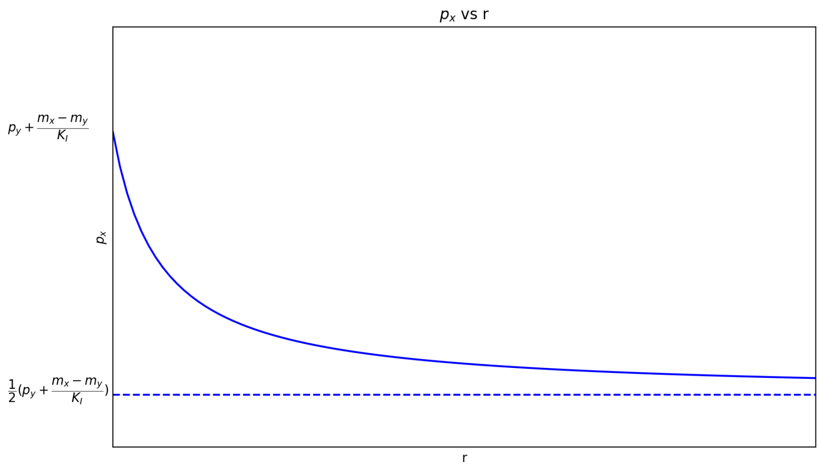

FIGURE 3. THE RELATION BETWEEN r AND p_x IN A ONE-SHOT GAME WITH FAIRNESS PREFERENCES

than $p_y + \frac{m_x - m_y}{k_I}$, the consumer chooses to "consume"; while if the dynamic price p_x is larger than $p_y + \frac{m_x - m_y}{k_I}$, the consumer's optimal choice would be "not consume".

If the consumer adopts "tit for tat" strategy, then we get:

- If $p_x < \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, the consumer will choose to "consume," denoted as a_1^1.
- If $\frac{1}{2}(p_y + \frac{m_x - m_y}{k_I}) < p_x < p_y + \frac{m_x - m_y}{k_I}$, the consumer will still "consume", but they will retaliate against the platform for the price higher than cooperative outcome (let the loss of the platform's next-period income for the retaliatory measure of the consumer be β)[4], and this strategy is denoted as a_1^2.
- If $p_x > p_y + \frac{m_x - m_y}{k_I}$, the consumer does not consume, denoted as a_1^3.

Given all the values within the range of $p_x < \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, and $\frac{1}{2}(p_y + \frac{m_x - m_y}{k_I}) < p_x < p_y + \frac{m_x - m_y}{k_I}$, , the consumer's strategies will be the same, which results in the same effect on the platform. In addition, all prices of $p_x > p_y + \frac{m_x - m_y}{k_I}$ give

[4]This is a repeated game with credible threat. The consumer's retaliatory measures mainly include: spreading negative remarks, "not consume." If they only spread negative remarks, $p_x - \beta > 0$; if only "not consume", $p_x - \beta = 0$; and if "not consume" and spread negative remarks at the same time, $p_x - \beta < 0$. The outcome of retaliation by the consumer can depend on a myriad of factors, including especially the consumer's social influence. This is difficult to model or predict in today's digital era. Therefore, in this model, we simply include it as a parameter, which is chosen by the platform.

zero profits to the platform. To maximize the platform's profits, the final optimal equilibrium prices will be set at: $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ or $p_x = p_y + \frac{m_x - m_y}{k_I}$.

Let the platform's discount factor be $\delta = \frac{1}{1+R}$, in which R is the discount rate, then its profit function will be:

If the platform chooses low price $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, the consumer will choose to "consume" every time. We have:

$$\begin{aligned} \pi_2(p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I}), a_1^1) &= \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})(1 + \delta + \delta^2 + ...) \\ &= \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})\frac{1}{1-\delta} \end{aligned} \tag{8}$$

If the platform chooses high price $p_x = p_y + \frac{m_x - m_y}{k_I}$, the consumer will choose to "consume", but retaliate the next time, then we have:

$$\begin{aligned} \pi_2(p_x = p_y + \frac{m_x - m_y}{k_I}, a_1^2) &= (p_y + \frac{m_x - m_y}{k_I})(1 + \delta + \delta^2 + ...) \\ &\quad + (-\beta)(\delta + \delta^2 + \delta^3 + ...) \\ &= \frac{1}{1-\delta}(p_y + \frac{m_x - m_y}{k_I}) - \frac{\delta\beta}{1-\delta} \end{aligned} \tag{9}$$

Comparing (8) and (9), we get the equilibrium solution of repeated game not incorporating fairness preferences: If $\delta > \frac{1}{2\beta}(p_y + \frac{m_x - m_y}{k_I})$, $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ (the low price); otherwise, $p_x = p_y + \frac{m_x - m_y}{k_I}$ (the high price).

Therefore, in a repeated game without fairness factors, when the loss of the platform resulted from the consumer's retaliation is larger (the greater the β is), the fair price $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ is more likely to be reached. Other parameters also have an effect on the pricing strategy. When the platform values future profits more (the larger the δ is), when the cost of "not consume" is smaller (the smaller the p_y and $m_x - m_y$) , or when k_I is larger or I is smaller, the fair price $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ will be reached more likely.

B. Repeated game incorporating fairness preferences

In repeated game, if a dynamic pricing p_1 is perceived by the consumer as unfair ($f_2^1 < 0$), and we assume the consumer has fairness preferences ($r > 0$), then she will retaliate against the platform to increase her total utility $U = \pi + \tilde{f}(1 + f)$, which, in the model, is reflected by the construction of $f_1 < 0$.

Theorem 2: When consider both platform and consumers' repeated games and consumers' fairness preferences, the greater consumers' fairness coefficient (the degree of fairness preference) is, the more likely the platform is to set the fair price and a lower equilibrium high price.

We still assume that the consumer adopts "tit-for-tat" strategies:

If $p_x < \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, the consumer will choose to "consume" each time, and will not feel treated unfairly, denoted as a_1^1. If the total utility of choosing "consume" is larger than "not consume" when fairness preferences are incorporated, but $f_2^1 = \frac{3}{2}r(\frac{1}{2} - \frac{p_x}{p_y + \frac{m_x - m_y}{k_I}}) < 0$, which is $p_x > \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, the consumer will choose to "consume" but retaliate against the platform out of fairness preferences, denoted as a_1^2. If the total utility of choosing to "consume" is less than "not consume" when fairness preferences are incorporated, that is, $p_x > (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$, the consumer will not consume, denoted as a_1^3.

Given that all the values are within the range of $\frac{1}{2}(p_y + \frac{m_x - m_y}{k_I}) < p_x < (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$, and $p_x < \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, the consumer's strategies will be the same, which results in the same impacts on the platform. In addition, all prices of $p_x > (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$ give zero profits to the platform. To maximize the platform's profits, the final optimal equilibrium prices will be $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ or $p_x = (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$.

Still assume the platform's discount factor be δ, then its profit function will be:

If the platform chooses low price $p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$, we have:

$$\begin{aligned} \pi_2(p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I}), a_1^1) &= \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})(1 + \delta + \delta^2 + \ldots) \\ &= \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})\frac{1}{1-\delta} \end{aligned} \tag{10}$$

If the platform chooses the high price $p_x = (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$, we have:

$$\begin{aligned} &\pi_2(p_x = (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I}), a_1^2) \\ &= (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})(1 + \delta + \delta^2 + \ldots) \\ &= (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})\frac{1}{1-\delta} - \frac{\delta\beta}{1-\delta} \end{aligned} \tag{11}$$

Comparing (10) and (11), we obtain the equilibrium solution of repeated game incorporating fairness factors:

If

$$\delta > \frac{p_y + \frac{m_x - m_y}{k_I}}{(2 + \frac{3r}{p_y k_I + m_x - m_y})\beta} \tag{12}$$

$p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$ (the low price/fair price); otherwise,

$$p_x = (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I}) \quad (\textit{the high price}) \tag{13}$$

According to (12) and (13), consumer's retaliatory measure only affects platform's critical value of discount factor.

Lemma 1: When consider both platform and consumers' repeated games and consumers' fairness preferences, the more extreme consumers' retaliatory measure is, the lower the critical value of platform's discount factor is, the more likely the platform is to set the fair price.

According to (12) and (13), the influence of Income (I) on platform's decision is categorized by consumer's fairness coefficient (r) and the cost of alternative choice ($m_x - m_y$).

Lemma 2: When consider both platform and consumers' repeated games and consumers' fairness preferences, when $r < \frac{2}{3}(m_x - m_y)$, the smaller the k_I is or the larger the I is, the lower the high price and the higher the fair price will be, while the lower the critical value is. When $\frac{2}{3}(m_x - m_y) < r < \frac{4}{3}(m_x - m_y)$, the smaller the k_I is or the larger the I is, the lower the high price and the higher the fair price will be, while the higher the critical value is. When $r > \frac{4}{3}(m_x - m_y)$, the smaller the k_I is or the larger the I is, the higher the equilibrium high price and fair price will be, while the higher the critical value is.

The equilibrium price p_x affect consumer's utility through its influence on consumer's consumption effectiveness and transaction effectiveness. When consumer's fairness coefficient (r) and income (I) is relatively large ($r > \frac{4}{3}(m_x - m_y)$, $k_I < \frac{1}{p_y}[\frac{3}{2}r - (m_x - m_y)]$), the marginal variation of consumption effectiveness (CE) on p_x is smaller than the marginal variation of transaction effectiveness (TE) on p_x while the marginal variation of consumption effectiveness (CE) on k_I is greater than the marginal variation of transaction effectiveness (TE) on k_I*. Compared with consumers with low income, consumers with higher income gain most of their utility from consumption effectiveness which is weakly influenced by price. Therefore, platform tend to set high price for consumers with high income while set fair price for consumers with low income.

Lemma 3: When consider both platform and consumers' repeated games and consumers' fairness preferences, the smaller cost of alternative choice (the smaller the p_y and $m_x - m_y$ are), the lower the platform's equilibrium price will set and the lower the critical value will be.

Another parameter that can contribute to the fair pricing is a greater loss of the platform resulted from the consumer's retaliation is larger (the greater the β is). Otherwise, the platform tends to set the high price, where $p_x = (\frac{1}{2} + \frac{1}{2 + \frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$.

C. Comparing repeated game basing on whether to incorporate fairness preferences

Theorem 3: Compared with one-shot game without fairness preferences, platform and consumer's repeated game and consumer's fairness preference can both urge the platform to set the fair price or lower the equilibrium high price.

Combining the equilibrium solutions of (8), (9), (10) and (11), we have:

$p_x = p_y + \frac{m_x - m_y}{k_I}$	The consumer doesn't have fairness preferences and $\delta < \frac{1}{2\beta}(p_y + \frac{m_x - m_y}{k_I})$;
$p_x = (\frac{1}{2} + \frac{1}{2+\frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$	The consumer has fairness preferences and $\delta < \frac{p_y + \frac{m_x - m_y}{k_I}}{(2+\frac{3r}{p_y k_I + m_x - m_y})\beta}$;
$p_x = \frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$	Fairness not incorporated and $\delta > \frac{1}{2\beta}(p_y + \frac{m_x - m_y}{k_I})$ or fairness incorporated and $\delta > \frac{p_y + \frac{m_x - m_y}{k_I}}{(2+\frac{3r}{p_y k_I + m_x - m_y})\beta}$;
$p_x = 0$	The price of perfect competition when the platform don' t have information superiority.

When the consumer doesn't have fairness preferences ($r = 0$), the platform have a small discount factor $\delta < \frac{1}{2\beta}(p_y + \frac{m_x - m_y}{k_I})$, the cost of choosing 'alternative goods/services' $m_x - m_y$ is high, or the loss of the platform's next-period income for the retaliatory measure of the consumer β is small, the platform will set the high dynamic price $p_y + \frac{m_x - m_y}{k_I}$. When the consumer has fairness preferences $r > 0$, the dynamic price p_x will fall between the fair price and the highest price where it obtains the entire surplus, and the specific value $(\frac{1}{2} + \frac{1}{2+\frac{3r}{p_y k_I + m_x - m_y}})(p_y + \frac{m_x - m_y}{k_I})$ depends on the consumer's valuation on fairness r. A higher r contributes to a lower dynamic price p_x. When the consumer has fairness preferences $r > 0$, the platform attach greater importance to future profits $\delta > \frac{p_y + \frac{m_x - m_y}{k_I}}{(2+\frac{3r}{p_y k_I + m_x - m_y})\beta}$, the cost of choosing 'alternative goods/services's is lower, the loss of the platform's next-period income for the retaliatory measure of the consumer β is larger, or when the consumer pays more attention to fairness (greater r), the platform will be more likely to set its price at a fair price $\frac{1}{2}(p_y + \frac{m_x - m_y}{k_I})$. Figure 4 illustrates this relationship.

VI. Conclusion

This paper applies fair game and repeated game theory to analyze dynamic pricing strategies adopted by platforms, as well as the relationship between dy-

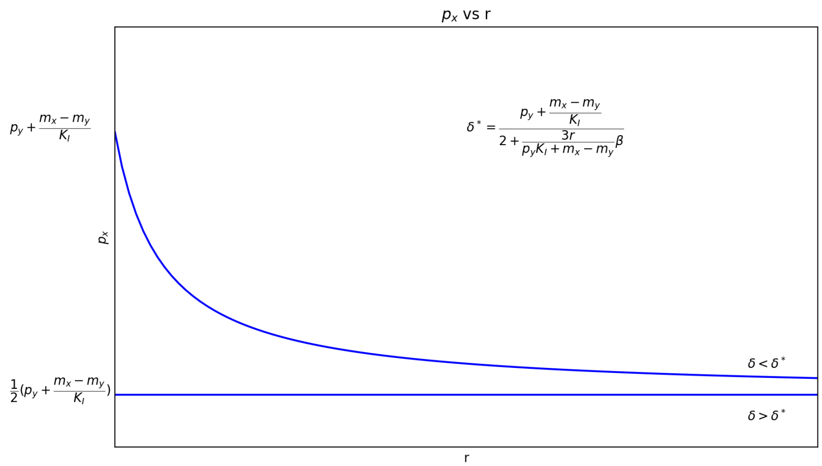

FIGURE 4. THE RELATION OF r AND p_x IN A REPEATED GAME WITH FAIRNESS PREFERENCES

namic prices and consumers' fairness preferences, income levels, the impact of consumers' retaliation on companies, alternative costs of switching to other substitute goods, and companies' discounting factors.

Our research reveals both fair game and repeated game will impact on the fair pricing. In a one-shot game, if consumers have fairness preferences, dynamic prices will slightly decline. Besides, in long-term repeated game, dynamic prices may also be reduced to fair prices if the platform values future profits enough. Moreover, when fairness preferences and repeated game are considered simultaneously, prices are most likely to be reduced to the fair price.

In addition, we prove that smaller platform's discount factors, less consumers' emphasis on fairness, weaker retaliation, higher income, and higher switching cost all lead to higher dynamic prices. The equilibrium prices will exceed the fair price, but will still be lower than the price under first-degree price discrimination (the specific value depends on the size of the parameter), vice versa.

In the platform economy era, complete information game has become prevalent with the development of the Internet and algorithms auditing techniques. Our research indicates that fair game and repeated game have important implications on business strategies, especially on dynamic pricing strategies. When consumers place great emphasis on fairness, or the companies attach great importance to the future profits, a sustainable strategy for the platform is to divide the consumer surplus fairly between the platforms and consumers.

Therefore, in a digital economy, managers should pay attention to consumers' fairness preferences when determining the dynamic pricing strategies. Meanwhile, consumers should develop fairness preferences to safeguard their rights and interests. From a social planner's perspective, it is important to enforce smooth interaction mechanism between consumers and platform companies, and foster platform competition to ensure consumers can credibly retaliate against platform's unfair pricing strategies.

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Mathematical Appendix

A1. Proof of Equation (4)

$$
\begin{aligned}
&U_1((1,0),p_x,(1,0))\\
&=\pi_1((1,0),p_x)+rf_2^1(p_x,(1,0))[1+f_1((1,0),p_x)]\\
&=\pi_1((1,0),p_x)+r\frac{\pi_1((1,0),p_x)-\pi_1^e((1,0))}{\pi_1^h((1,0))-\pi_1^{min}((1,0))}(1+\frac{\pi_2(p_x,(1,0))-\pi_2^e(p_x)}{\pi_2^h(p_x)-\pi_2^{min}(p_x)})\\
&=u_1((1,0),p_x)+r\frac{u_1((1,0),p_x)-\frac{u_1((1,0),0)+u_1((1,0),s)}{2}}{u_1((1,0),0)-u_1((1,0),s)}(1+\frac{\pi_2(p_x,(1,0))-\pi_2^e(p_x)}{\pi_2^h(p_x)-\pi_2^{min}(p_x)})\\
&=m_x-k_Ip_x+r\frac{m_x-k_Ip_x-\frac{1}{2}(m_x+(m_y-k_Ip_y))}{m_x-(m_y-k_Ip_y)}(1+\frac{p_x-\frac{1}{2}(p_x+0)}{p_x-0})\\
&=m_x-k_Ip_x+\frac{3}{2}r\frac{-k_Ip_x+\frac{1}{2}k_Ip_y+\frac{1}{2}m_x-\frac{1}{2}m_y}{k_Ip_y+m_x-m_y}\\
&=m_x-k_Ip_x+\frac{3}{2}r(\frac{1}{2}-\frac{p_x}{p_y+\frac{m_x-m_y}{k_I}})
\end{aligned}
$$

A2. Proof of Theorem 5

1. Equilibrium high price

$$
\begin{aligned}
p_x&=(\frac{1}{2}+\frac{1}{2+\frac{3r}{p_yk_I+m_x-m_y}})(p_y+\frac{m_x-m_y}{k_I})\\
&=p_y+\frac{m_x-m_y}{k_I}-\frac{3r(p_y+\frac{m_x-m_y}{k_I})}{4p_yk_I+4(m_x-m_y)+6r}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial p_x}{\partial k_I}&=-\frac{m_x-m_y}{k_I^2}+\frac{\frac{3r(m_x-m_y)}{k_I^2}[4p_yk_I+4(m_x-m_y)+6r]+4p_y\cdot 3r(p_y+\frac{m_x-m_y}{k_I})}{[4p_yk_I+4(m_x-m_y)+6r]^2}\\
&=-\frac{m_x-m_y}{k_I^2}+\frac{3r(m_x-m_y)}{k_I^2[4p_yk_I+4(m_x-m_y)+6r]}+\frac{12rp_y(p_yk_I+m_x-m_y)}{k_I[4p_yk_I+4(m_x-m_y)+6r]^2}
\end{aligned}
$$

Let $\frac{\partial p_x}{\partial k_I}=0$, simplify the equation and get:

$$
\begin{aligned}
&2p_y^2[4(m_x-m_y)-3r]k_I^2+4p_y(m_x-m_y)[4(m_x-m_y)+3r]k_I\\
&+(m_x-m_y)[2(m_x-m_y)+3r][4(m_x-m_y)+3r]=0
\end{aligned}
$$

$$k_I^* = \frac{-4p_y(m_x - m_y)\Big[4(m_x - m_y) + 3r\Big]}{4p_y^2\Big[4(m_x - m_y) - 3r\Big]} + \frac{2p_y}{4p_y^2[4(m_x - m_y) - 3r]}\Bigg\{4(m_x - m_y)^2\Big[4(m_x - m_y) + 3r\Big]^2 - 2(m_x - m_y)\Big[4(m_x - m_y) - 3r\Big]\Big[2(m_x - m_y) + 3r\Big]\Big[4(m_x - m_y) + 3r\Big]\Bigg\}^{1/2}$$

If $r < \frac{4}{3}(m_x - m_y)$, $\frac{\partial p_x}{\partial k_I} > 0$ in $k_I \in (0, +\infty)$; if $r > \frac{4}{3}(m_x - m_y)$, $\frac{\partial p_x}{\partial k_I} < 0$ in $k_I \in (0, +\infty)$.

2. Critical value

$$\delta = \frac{p_y + \frac{m_x - m_y}{k_I}}{(2 + \frac{3r}{p_y k_I + m_x - m_y})\beta} = \frac{P_y^2 k_I + \frac{(m_x - m_y)^2}{k_I} + 2P_y(m_x - m_y)}{[2P_y k_I + 2(m_x - m_y) + 3r]\beta}$$

Let $\frac{\partial \delta}{\partial k_I} = 0$, simplify the equation and get:

$$p_y^2[2(m_x - m_y) - 3r]k_I^2 + 4p_y(m_x - m_y)^2 k_I + (m_x - m_y)^2[2(m_x - m_y) + 3r] = 0$$

$$\delta^* = \frac{-2p_y(m_x - m_y)^2}{p_y^2\Big[2(m_x - m_y) - 3r\Big]} + \frac{p_y}{p_y^2\Big[2(m_x - m_y) - 3r\Big]}\Bigg\{4(m_x - m_y)^4 - (m_x - m_y)^2\Big[2(m_x - m_y) - 3r\Big]\Big[2(m_x - m_y) + 3r\Big]\Bigg\}^{1/2}$$

If $\delta < \frac{2}{3}(m_x - m_y)$, $\frac{\partial \delta}{\partial k_I} > 0$ in $k_I \in (0, +\infty)$; if $\delta > \frac{2}{3}(m_x - m_y)$, $\frac{\partial \delta}{\partial k_I} < 0$ in $k_I \in (0, +\infty)$.

*A3. Proof of statement **

$CE = m_x - k_I p_x$
$TE = \frac{3}{2}r(\frac{1}{2} - \frac{p_x}{p_y + \frac{m_x - m_y}{k_I}})$

1. Marginal variation on p_x.

$$\frac{\partial CE}{\partial p_x} = -k_I$$

$$\frac{\partial TE}{\partial p_x} = -\frac{\frac{3}{2}r}{p_y + \frac{m_x - m_y}{k_I}}$$

When $k_I < \frac{1}{p_y}[\frac{3}{2}r - (m_x - m_y)]$, $|\frac{\partial CE}{\partial p_x}| < |\frac{\partial TE}{\partial p_x}|$
When $k_I > \frac{1}{p_y}[\frac{3}{2}r - (m_x - m_y)]$, $|\frac{\partial CE}{\partial p_x}| > |\frac{\partial TE}{\partial p_x}|$

2. Marginal variation on k_I.

$$\frac{\partial CE}{\partial k_I} = -p_x$$

$$\frac{\partial TE}{\partial k_I} = -p_x \frac{\frac{3}{2}r(m_x - m_y)}{(p_y k_I + m_x - m_y)^2}$$

If $|\frac{\partial CE}{k_I}| > |\frac{\partial TE}{k_I}|$, then $\frac{\frac{3}{2}r(m_x-m_y)}{(p_y k_I+m_x-m_y)^2} < 1$
Simplify the equation and get:

$$2p_y^2 k_I^2 + 4p_y(m_x - m_y)k_I + [2(m_x - m_y) - 3r](m_x - m_y) > 0$$

If $r > \frac{2}{3}(m_x - m_y)$, the solution is $k_I > 0$.