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Input price discrimination and upstream R&D investments

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Abstract

We study the welfare effects of input price discrimination when an upstream supplier that secretly contracts with two cost-asymmetric downstream firms undertakes R&D investments. We show that a ban on input price discrimination increases (decreases) the level of upstream R&D investments when downstream cost-asymmetry is relatively low (high). Nevertheless, we find that welfare always decreases after the ban. Thus, input price discrimination should be welcomed rather than prohibited even when it stifles the upstream supplier's incentives to engage in cost-reduction activities.

Keywords: Input price discrimination; R&D investments; vertical contracting; welfare

JEL Classification: D43; K21; L11; L42

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1. Introduction

Price discrimination by big manufacturers is an important issue in competition policy. In the pharmaceutical industry, for instance, several retail pharmacies in the US alleged that big drug manufacturers, such as *Johnson & Johnson* and *American Home Products*, offer lower prices to certain purchasers thereby engaging in unlawful price discrimination under the Robinson-Patman Act (*Drug Mart Pharmacy Corp., et al. v. American Home Products Corp., et al.*; case number 12-4689-cv).¹

There is by now a large theoretical literature on the welfare effects of price discrimination in input markets (see e.g., Katz, 1987; DeGraba, 1990; O'Brien & Shaffer, 1994; Yoshida, 2000; Caprice, 2006; Rey & Tirole, 2007; Inderst & Valletti, 2009; Inderst & Shaffer, 2009; O'Brien, 2014; Herweg & Müller, 2012, 2014, 2016).² All aforementioned studies abstract from the possibility that upstream suppliers engage in cost-reduction activities. However, investing in R&D is a common business practice by many big manufacturers; for instance, *Johnson & Johnson*, which was involved in the aforementioned antitrust case, is reported to be one of the top spenders in the pharmaceutical industry.³ Therefore, this paper aims to add to the existing literature by considering the case of upstream R&D investments.

We examine the long-run effects of input price discrimination in a model with an upstream supplier and two cost-asymmetric downstream firms. Following Rey & Tirole (2007), we assume unobservable two-part tariff contracts. We show that a ban on input price discrimination increases or decreases the equilibrium level of upstream R&D investments depending on the degree of downstream cost-asymmetry. Yet, we find that welfare always decreases after the ban. Therefore, input price discrimination should be welcomed rather than prohibited even when it decreases the upstream supplier's incentives to engage in cost-reduction activities.

A ban on input price discrimination has two effects on the upstream supplier's incentives to invest in R&D. The first effect, which we label as the “*elimination of commitment problem effect*”, is positive. Under discriminatory pricing, and due to contract unobservability, once a downstream firm has signed a contract, the upstream supplier has an incentive to offer better terms to the other competitor (Hart & Tirole, 1990; Rey & Tirole, 2007). A ban on input price

¹Regarding legal treatment, input price discrimination issues arise in the context of the Robinson-Patman Act under US law and Article 102 of the Treaty on the Functioning of the European Union (TFEU) under EU law.

²See Herweg & Müller (2012, 2016), as well as Chen (2017), for brief but informative reviews of this literature.

³Michael Casey, Robert Hackett (2014, November 17). Retrieved from <http://fortune.com/2014/11/17/top-10-research-development>.

discrimination eliminates contract unobservability and the supplier's associated opportunism problem (since it requires both downstream firms receiving the same offer) thus increasing the value of inducing a given cost-reduction.

The second effect, which we label as the “*nonappropriability of industry profits effect*”, is negative. Under discriminatory pricing the supplier can appropriate all downstream profits, however, under non-discriminatory pricing it cannot do so due to the common fixed fee – it must leave a positive rent to the more cost-efficient downstream firm. Hence, a ban on input price discrimination decreases the value of inducing a given cost-reduction.

The lower is the cost-asymmetry between downstream firms, the lower is the rent left to the more cost-efficient downstream firm and thus the more likely is that the “elimination of commitment problem effect” will dominate the “nonappropriability of industry profits effect” implying that a ban on input price discrimination will increase the level of upstream R&D investments.

As is well-known, a ban on input price discrimination increases both input prices – since it offers the supplier the opportunity to make commitments thereby solving its opportunism problem – and thus decreases welfare in the short-run (O'Brien & Shaffer, 1994; Rey & Tirole, 2007). As it turns out, at least for the case of linear demand, this effect on input prices is strong enough so that banning input price discrimination also decreases welfare in the long-run *even though* it may increase the upstream supplier's incentives to invest in R&D.

It is a common presumption that whenever a ban on input price discrimination increases (decreases) firm's incentives to invest in R&D, it also increases (decreases) welfare in the long-run. Whereas the existing literature shows that this presumption is indeed true for the case of downstream R&D investments (DeGraba, 1990; Inderst & Valletti, 2009; Herweg & Müller, 2014), we show that it may *not* necessarily be true for the case of upstream R&D investments. Therefore, our research aims to raise competition-policy authorities' awareness of the fact that certain conclusions regarding the desirability of practicing input price discrimination when downstream firms engage in R&D need not carry over to the case where it is the upstream supplier that invests in cost reductions.

The rest of the paper is organized as follows. Section 2 introduces the key elements of our model. Sections 3 and 4 deal with the cases of discriminatory and non-discriminatory pricing respectively. Section 5 contains the concluding remarks.

2. The analytical framework

We consider a vertically related industry consisting of one upstream and two downstream firms denoted, respectively, by U and D_i with $i=1,2$. Each downstream firm purchases an intermediate good (input) from U , transforms it into a differentiated final-good in a one-to-one proportion and sells it to consumers. Consumers' inverse demand for D_i 's final good is given by

$$p_i = a - q_i - \theta q_j, \quad i, j = 1, 2, \quad i \neq j, \quad (1)$$

where the parameter $\theta \in [0,1]$ indexes the degree of product substitutability. When θ equals zero final goods are independent in demand whereas when θ equals unity final goods are perfect substitutes (homogeneous).

The upstream firm owns a research lab where it invests in order to reduce the cost of producing the input. Specifically, the unit production cost of the input is $c_U - x$, $a > c_U > 0$, where c_U is an initial exogenous cost and x are U 's R&D investments. Following d'Aspremont & Jacquemin (1988), we assume that R&D investments are subject to diminishing returns as captured by the quadratic form of R&D cost: mx^2 . The cost parameter $m > 1/2$ reflects the efficiency of R&D expenditures.⁴ Downstream firms face constant marginal cost of producing and selling their goods c_i with $i=1,2$. Without loss of generality, we set $c_2 = c_D > c_1 = 0$, i.e., we assume that D_1 is more cost-efficient than D_2 and its marginal cost is zero, so that c_D denotes the production cost advantage of D_1 .

Under discriminatory input pricing, the timing of the game is as follows. At the first stage, the upstream supplier chooses the level of R&D investments, x . The choice of x , and thus the supplier's resulting marginal cost, is observable by downstream firms.⁵ At the second stage, the upstream supplier, simultaneously and secretly, makes each downstream firm a take-it-or-leave-it offer. We focus on two-part tariffs, consisting of a per-unit input price w_i and a fixed fee F_i . At the third stage, downstream firms compete in quantities (Cournot competition).

⁴The latter guarantees that second-order conditions are satisfied in all cases under consideration.

⁵For instance, pharmaceutical companies have long been under great pressure by the U.S. government to disclose information about their costs at the wholesale level (thus aiming to make them justify their prices). According to the Philadelphia Inquirer, in a speech to pharmaceutical executives, former U.S. President Bill Clinton, said: "Explain, explain, explain and disclose, disclose, disclose" (Andrew Pollack (2015, July 23). *The New York Times*. Retrieved from <http://www.nytimes.com>). Nonetheless, our results carry over to the case where R&D investments are unobservable by downstream firms.

Due to contract unobservability, when dealing with one of the downstream firms, the upstream supplier has an incentive to cheat on the other competitor (Hart & Tirole, 1990). Multiple equilibria can arise in this setting due to the multiplicity of beliefs that downstream firms can form when they receive out-of-equilibrium offers. Following Hart & Tirole (1990), McAfee & Schwartz (1994) and Rey & Tirole (2007), we assume “*passive*” beliefs – also called “*market-by-market*” conjectures – which imply that when a downstream firm receives an out-of-equilibrium offer from U , it does not revise its beliefs about the offer received by its rival.⁶

When input price discrimination is banned, the two downstream firms must receive the same contract offer, consisting of a common input price and a common fixed fee.⁷ In such case, the game unfolds as described above, with the exception that now contracts are observable by downstream firms.⁸

We make the following two assumptions throughout this paper:

Assumption 1. $c_D < \bar{c}_D = \frac{2(a - c_U)m(2 - \theta)}{m(6 + \theta) - 1},$

Assumption 2. $\frac{c_U}{a} > \frac{1}{2m(1 + \theta)}.$

Assumption 1 requires that the production cost advantage of D_I over D_2 is not too high and guarantees that both downstream firms will produce a positive quantity of the final-good in all cases under consideration. Assumption 2 requires that the initial upstream marginal cost c_U is not too low relative to the market size a , guaranteeing that the upstream firm’s marginal cost is always nonnegative. For notational reasons, we use superscripts D and U to denote, respectively, the equilibrium values under discriminatory and uniform (non-discriminatory) pricing.

⁶From the perspective of the upstream supplier, when contracts are unobservable and downstream competition is in quantities, the two downstream firms form two separate markets. Therefore, a passive-beliefs equilibrium survives both unilateral and multilateral deviations (for more details see Rey & Vergé (2004) and Rey & Tirole (2007)).

⁷As noted by Inderst & Shaffer (2009), the fact that the upstream supplier offers a single two-part tariff to both downstream firms implies that the latter will pay the same marginal input price and thus compete on the same “level playing field” as required by the Robinson-Patman Act under US law and the Article 102 of the Treaty on the Functioning of the European Union (TFEU) under EU law.

⁸Alternatively, we could have assumed that contracts are still secret however downstream firms now hold “*symmetric*” beliefs: following any out-of-equilibrium contract offer, a downstream firm believes that its rival receives the same deviation contract. As is well-known, with symmetric beliefs, the upstream supplier can achieve the same equilibrium outcomes as if contracts were observable.

3. Input price discrimination

We start our analysis by considering the case where input price discrimination is practiced. With passive beliefs, and for any given level of R&D investments, each downstream firm anticipates that its rival receives the equilibrium offer and thus puts the equilibrium quantity on the market. Therefore, each downstream firm chooses its quantity in order to maximize its gross profits:

$$\max_{q_1} \pi_{D_1} = (a - q_1 - \theta q_2^D(x) - w_1)q_1, \quad \max_{q_2} \pi_{D_2} = (a - q_2 - \theta q_1^D(x) - w_2 - c_D)q_2. \quad (2)$$

Quantities at the last-stage subgame respond only to changes in the own input price according to the downstream best-response functions:

$$q_1^D(w_1) = \frac{a - w_1 - \theta q_2^D(x)}{2}, \quad q_2^D(w_2) = \frac{a - (w_2 + c_D) - \theta q_1^D(x)}{2}. \quad (3)$$

Prices at the last-stage subgame also respond only to changes in the own input price:

$$p_1^D(q_1^D(w_1), q_2^D(x)), \quad p_2^D(q_1^D(x), q_2^D(w_2)). \quad (4)$$

Since each downstream firm accepts the contract offer as long as the corresponding profit is nonnegative, the upstream supplier uses the fixed fee to extract all downstream profits, i.e.,

$$F_1 = [p_1^D(q_1^D(w_1), q_2^D(x)) - w_1]q_1^D(w_1), \quad F_2 = [p_2^D(q_1^D(x), q_2^D(w_2)) - w_2 - c_D]q_2^D(w_2), \quad (5)$$

and sets input prices in order to maximize industry profits:

$$\begin{aligned} \max_{w_1, w_2} \pi_U = & [p_1^D(q_1^D(w_1), q_2^D(x)) - (c_U - x)]q_1^D(w_1) + \\ & + [p_2^D(q_1^D(x), q_2^D(w_2)) - c_D - (c_U - x)]q_2^D(w_2) - mx^2. \end{aligned} \quad (6)$$

From the first order conditions of (6), and using (3), we obtain the input prices and final-good outputs for given levels of R&D investments:

$$w_1^D(x) = w_2^D(x) = w^D(x) = c_U - x, \quad (7)$$

$$q_1^D(x) = \frac{(a - c_U + x)(2 - \theta) + \theta c_D}{4 - \theta^2}, \quad q_2^D(x) = \frac{(a - c_U + x)(2 - \theta) - 2c_D}{4 - \theta^2}. \quad (8)$$

When contracts are unobservable and downstream firms hold passive beliefs, the upstream supplier's contract offer to any downstream firm do not affect the downstream rival firm's quantity – as can be seen from (6), the two contracts affect the upstream supplier's profits in a separable way – and thus the contract terms are chosen as to maximize joint profits of each specific bilateral relation, instead of total industry profits. Hence, all downstream firms pay the input at its marginal cost, regardless of their relative efficiency. (O'Brien & Shaffer, 1994; Rey & Tirole, 2007).⁹

The upstream supplier chooses the level of R&D investments in order to maximize:

$$\begin{aligned} \max_x \pi_U = & [p_1^D(q_1^D(x), q_2^D(x)) - (c_U - x)]q_1^D(x) + \\ & + [p_2^D(q_1^D(x), q_2^D(x)) - c_D - (c_U - x)]q_2^D(x) - mx^2. \end{aligned} \quad (9)$$

From the first order condition of (9), we obtain the equilibrium level of R&D investments when input price discrimination is practiced:

$$x^{D*} = \frac{2(a - c_U) - c_D}{m(2 + \theta)^2 - 2} > 0, \quad (10)$$

where the positive sign stems from Assumption 1 and the fact that $m > 1/2$.

4. Banning input price discrimination

⁹As noted by O'Brien & Shaffer (1994), even though marginal input prices are the same for both downstream firms, average prices paid for the upstream supplier's product are *not* the same since they depend on both the fixed fees and the quantity purchased by each downstream firm in equilibrium.

We now investigate the effects of a ban on input price discrimination on consumer surplus and welfare. The two downstream firms receive the same two-part tariff contract, consisting of a common input price and a common fixed fee. Contract offers are now observable by downstream firms; banning input price discrimination offers the supplier the opportunity to make commitments, thus solving its opportunism problem.

Each downstream firm chooses its quantity in order to maximize its gross profits:

$$\max_{q_1} \pi_{D_1} = (a - q_1 - \theta q_2 - w)q_1, \quad \max_{q_2} \pi_{D_2} = (a - q_2 - \theta q_1 - w - c_D)q_2. \quad (11)$$

From the first order conditions of (11), we obtain quantities at the last-stage subgame for any given level of the input price:

$$q_1^U(w) = \frac{(a - w)(2 - \theta) + \theta c_D}{4 - \theta^2}, \quad q_2^U(w) = \frac{(a - w)(2 - \theta) - 2c_D}{4 - \theta^2}. \quad (12)$$

Due to downstream cost-asymmetry, the upstream supplier cannot extract all downstream profits through the common fixed fee. Since it is the less cost-efficient downstream firm's participation constraint that is binding, the upstream supplier sets the common fixed fee equal to that firm's profits - thereby leaving the more cost-efficient firm with a rent - and thus chooses the common input price w so as to maximize its upstream profits plus twice the profits of the less cost-efficient downstream firm:

$$\begin{aligned} \max_w \pi_U = & [w - (c_U - x)][q_1^U(w) + q_2^U(w)] + \\ & + 2[p_2(q_1^U(w), q_2^U(w)) - c_D - w]q_2^U(w) - mx^2. \end{aligned} \quad (13)$$

From the first order condition of (13), and using (12), we obtain the common input price and final-good quantities as functions for given levels of R&D investments:

$$w^U(x) = \frac{2(2 - \theta)[a\theta + (c_U - x)(2 - \theta)] + c_D(4 + \theta^2)}{4(2 - \theta)(1 + \theta)}, \quad (14)$$

$$q_1^U(x) = \frac{2(a - c_U + x)(2 - \theta) - c_D(2 - 3\theta)}{4(2 - \theta)(1 + \theta)}, \quad q_2^U(x) = \frac{2(a - c_U + x)(2 - \theta) - c_D(6 + \theta)}{4(2 - \theta)(1 + \theta)}. \quad (15)$$

From (7) and (14), we have

$$w^U(x) - w^D(x) = \frac{2\theta(a - c_U + x)(2 - \theta) + c_D(4 + \theta^2)}{4(2 - \theta)(1 + \theta)} > 0.$$

When input price discrimination is feasible, input prices are equal to upstream marginal cost. A ban on input price discrimination eliminates the upstream supplier's commitment problem by making contracts observable, which leads to an increase in both input prices and thus to a reduction in both consumer surplus and welfare (O'Brien & Shaffer, 1994; Rey & Tirole, 2007).

The upstream supplier chooses the level of R&D investments in order to maximize:

$$\begin{aligned} \max_x \pi_U = & [w^U(x) - (c_U - x)][q_1^U(x) + q_2^U(x)] + \\ & + 2[p_2(q_1^U(x), q_2^U(x)) - c_D - w^U(x)]q_2^U(x) - mx^2. \end{aligned} \quad (16)$$

From the first order condition of (16), we obtain the equilibrium level of R&D investments when input price discrimination is banned:

$$x^{U*} = \frac{2(a - c_U)(2 - \theta) - c_D(4 - \theta)}{2(2 - \theta)[2m(1 + \theta) - 1]}. \quad (17)$$

where the positive sign stems from Assumption 1 and the fact that $m > 1/2$.

By comparing the equilibrium levels of upstream R&D investments in (10) and (17), we obtain the following result.

Proposition 1. *A ban on input price discrimination increases (decreases) the equilibrium level of upstream R&D investments when*

$$c_D < (>) \tilde{c}_D = \frac{2(a - c_U)m(2 - \theta)\theta^2}{m[8(1 + \theta) + \theta^2(4 - \theta)] - 4}.$$

A ban on input price discrimination has two effects on the upstream supplier's incentives to invest in R&D. The first effect, labelled "*elimination of commitment problem effect*", is positive. Banning input price discrimination eliminates the upstream supplier's opportunism problem and thus increases the value of inducing a given cost-reduction. The second effect, labelled "*nonappropriability of industry profits effect*", is negative. Contrary to the case of discriminatory pricing, the upstream supplier cannot extract all downstream profits under uniform pricing due to the common fixed fee and thus a ban on input price discrimination decreases the value of inducing a given cost-reduction. The former effect outweighs (is outweighed by) the latter when the degree of downstream cost-asymmetry is relatively low (high). The lower (higher) is the cost-asymmetry between downstream firms, the lower (higher) is the rent left to the more cost-efficient firm and thus the more (less) likely is that a ban on input price discrimination will increase the equilibrium level of upstream R&D investments.

With the possibility that the R&D investment levels being higher under uniform pricing than under discriminatory pricing, it seems likely that a ban on input price discrimination will decrease input prices and increase consumer surplus and welfare in the long-run. However, the following Proposition shows that this is *not* the case.

Proposition 2. *The common input price lies above the otherwise prevailing discriminatory input prices and a ban on input price discrimination always decreases consumer surplus and welfare.*

A ban on input price discrimination has two effects on input prices and thus on consumer surplus. First, for any given upstream marginal cost (exogenous upstream R&D investments), it eliminates the upstream supplier's opportunism problem thus pushing input prices upwards (O'Brien & Shaffer, 1994; Rey & Tirole, 2007). Second, as indicated in Proposition 1, it may increase the level of upstream R&D investments when downstream cost-asymmetry is relatively low thus pushing input prices downwards. As it turns out, at least for the case of linear demand, the former effect is strong enough so that input prices increase and consumer surplus decrease as a result of the ban despite the increase in upstream R&D levels.

A welfare comparison is more complicated than the previous analysis regarding consumer surplus since a higher (lower) level of R&D investments also implies a higher (lower) level of R&D expenditures. The latter affects total welfare but not consumer surplus. Nevertheless, Proposition 2 indicates that the effect of a higher or lower level of R&D expenditures on total

welfare is weak enough so that the effects of banning input price discrimination on consumer surplus and total welfare coincide.

From Propositions 1 and 2, we obtain the following important observation.

Corollary 1. *A ban on input price discrimination decreases consumer surplus and welfare even when it increases the upstream supplier's incentives to invest in R&D.*

By considering the case of downstream R&D investments, DeGraba (1990), Inderst & Valletti (2009) and Herweg & Müller (2014) show that a ban on input price discrimination increases or decreases welfare in the long-run depending on whether it increases or decreases downstream firm's incentives to invest in R&D. Our analysis suggests that certain conclusions regarding the desirability of practicing input price discrimination when downstream firms engage in R&D may *not* carry over to the case where it is the upstream supplier that invests in cost reductions.

5. Conclusions

In this paper, we have studied the welfare effects of price discrimination in input markets when an upstream supplier that secretly contracts with two cost-asymmetric downstream firms undertakes R&D investments. We have shown that a ban on discrimination increases (decreases) the level of upstream R&D investments when downstream cost-asymmetry is relatively low (high). Nevertheless, we have also found that consumer surplus and welfare always decrease after the ban. Consequently, input price discrimination should be welcomed rather than prohibited even when it decreases the upstream supplier's incentives to engage in cost-reduction activities.

Appendix

Proof of Proposition 1. From (10) and (17), we calculate,

$$x^{U*} - x^{D*} = \frac{2(a - c_U)m(2 - \theta)\theta^2 - c_D[m(8(1 + \theta) + \theta^2(4 - \theta)) - 4]}{[m(2 + \theta)^2 - 2][2(2 - \theta)(2m(1 + \theta) - 1)]},$$

where the denominator is positive due to the fact that $m > 1/2$. Thus, the above expression is positive (negative) whenever its numerator is positive (negative), i.e.,

$$c_D < (>) \tilde{c}_D = \frac{2(a - c_U)m(2 - \theta)\theta^2}{m[8(1 + \theta) + \theta^2(4 - \theta)] - 4}.$$

It can be easily checked that, for $m > 1/2$, it holds that $\tilde{c}_D < \bar{c}_D$. Therefore, a ban on input price discrimination increases (decreases) the level of upstream R&D investments when the degree of downstream cost-asymmetry is low (high). ■

Proof of Proposition 2. First, we calculate the final equilibrium outcomes for the two pricing regimes.

Discriminatory input pricing. Substituting (10) into (7) and (8), we have:

$$w_1^{D*} = w_2^{D*} = w^{D*} = c_U - \frac{2(a - c_U) - c_D}{m(2 + \theta)^2 - 2}, \quad (\text{A1})$$

$$q_1^{D*} = \frac{m(a - c_U)(4 - \theta^2) + c_D[m\theta(2 + \theta) - 1]}{(2 - \theta)[m(2 + \theta)^2 - 2]}, \quad (\text{A2})$$

$$q_2^{D*} = \frac{m(a - c_U)(4 - \theta^2) - c_D[2m(2 + \theta) - 1]}{(2 - \theta)[m(2 + \theta)^2 - 2]}.$$

Non-discriminatory input pricing. Substituting (17) into (14) and (15), we have:

$$w^{U*} = \frac{2a(2 - \theta)(m\theta - 1) + 2mc_U(4 - \theta^2) + c_D[m(4 + \theta^2) + (2 - \theta)]}{2(2 - \theta)[2m(1 + \theta) - 1]}, \quad (\text{A3})$$

$$q_1^{U*} = \frac{2m(a - c_U)(2 - \theta) - c_D[m(2 - 3\theta) + 1]}{2(2 - \theta)[2m(1 + \theta) - 1]}, \quad (\text{A4})$$

$$q_2^{U*} = \frac{2m(a - c_U)(2 - \theta) - c_D[m(6 + \theta) - 1]}{2(2 - \theta)[2m(1 + \theta) - 1]}.$$

Using (A1) and (A3), we first show that the common input price lies above the otherwise prevailing discriminatory input prices, i.e.,

$$w^{U*} - w^{D*} = \frac{(a - c_U)m(2 - \theta)\theta[m(2 + \theta) - 1] + c_D[m(2 + \theta)(4 + \theta^2) - (4 - 2\theta + \theta^2)]}{[m(2 + \theta)^2 - 2][2(2 - \theta)(2m(1 + \theta) - 1)]} > 0.$$

where the positive sign stems from the fact that $m > 1/2$.

Since final-good prices increase with the input price and the utility of the representative consumer is lower for higher final-good prices, it is straightforward that consumer surplus decreases as a result of the ban.

Total welfare is defined as the sum of consumer surplus and industry profits, i.e.,

$$TW^{k*} = \frac{(q_1^{k*})^2 + (q_2^{k*})^2 + 2\theta q_1^{k*} \tilde{q}_2^{k*}}{2} + (a - q_1^{k*} - \theta q_2^{k*})q_1^{k*} + (a - q_2^{k*} - \theta q_1^{k*} - c_D)q_2^{k*} - (c_U - x)(q_1^{k*} + q_2^{k*}) - mx^2,$$

with $k = D, U$. Define $\Delta TW^* = TW^{D*} - TW^{U*}$. Solving $\Delta TW^* = 0$ for c_D we obtain two roots:

$$c_{D(1,2)} = \frac{2(a - c_U)(2 - \theta)[\pm 2(2m(1 + \theta) - 1)(m(2 + \theta) - 2)\sqrt{A} + m(m^2 B - mC + D)]}{16 + m(m^2 E + m\theta G - H)}.$$

with

$$A = m[m(2 + \theta)^2 + \theta(4 + 3\theta + \theta^2)] > 0, \quad B = m^2(1 + \theta)(2 + \theta)^2(8 + 4\theta^2 + \theta^3) > 0,$$

$$C = 8(1 + \theta)(4 + \theta^2) + 3\theta^4(2 + \theta) > 0, \quad D = 8 - \theta^2(2 + \theta)(1 - \theta) > 0,$$

$$E = (1 + \theta)(2 + \theta)^2(4 + \theta^2)(4 - 4\theta - \theta^2) > 0, \quad G = 128 + 176\theta + 64\theta^2 + 8\theta^3 + 3\theta^5 > 0,$$

$$H = 48 + 80\theta + 28\theta^2 - 4\theta^3 - \theta^4 + \theta^5 > 0.$$

After some straightforward but tedious calculations, it can be verified that, for all $\theta \in [0, 1]$ and $m > 1/2$, both these roots lie outside the interval $(0, \bar{c}_D)$ implying that ΔTW^* has the same sign in that interval. It then suffices to show that

$$\Delta TW^* \Big|_{c_D \rightarrow 0, \theta \rightarrow 1} = \frac{(a - c_U)^2 m^2 (90m - 55m + 8)}{(9m - 2)^2 (4m - 1)^2} > 0.$$

where the positive sign stems from the fact that $m > 1/2$. Therefore, a ban on input price discrimination decreases total welfare. ■

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