Received: 6 September 2023 | Revised: 8 January 2024 | Accepted: 22 January 2024

DOI: 10.1111/manc.12471

ORIGINAL ARTICLE

The Manchester School WILEY

Bertrand-Cournot profit reversal under non-commitment process innovation

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Abstract

We provide a new reason for Bertrand-Cournot profit reversal. In a symmetric oligopoly, we show that firms get higher profits under Bertrand competition compared to Cournot competition under non-commitment process innovation if the products are sufficiently differentiated and there is positive knowledge spillover. As the number of firms increases, the degree of product differentiation over which the profits are higher under Bertrand competition can increase. Higher outputs under Bertrand competition compared to Cournot competition generate higher R&D investments under the former than the latter, which is responsible for our result.

KEYWORDS

Bertrand competition, Cournot competition, non-commitment R&D, process innovation

JEL CLASSIFICATION

D43, L10, L13

1 | INTRODUCTION

The seminal paper by Singh and Vives (1984) suggests that the profits are higher under Cournot competition while welfare is higher under Bertrand competition. The literature following Singh and Vives (1984) shows that the profits can be higher under Bertrand competition compared to

Cournot competition in the presence of asymmetric costs (Acharyya & Marjit, 1998; Zanchettin, 2006), more than two firms (Häckner, 2000), strategic input price determination (Arya et al., 2008; López, 2007; López & Naylor, 2004; Mukherjee et al., 2012), technology licensing (Mukherjee, 2010), and endogenous product differentiation (Brander & Spencer, 2022).

In this paper we provide a new reason for Bertrand-Cournot profit differential. We show that firms get higher profits under Bertrand competition compared to Cournot competition under non-commitment[1] process innovation if the products are sufficiently differentiated and there is positive knowledge spillover.[2] As the number of firms increases, the degree of product differentiation over which the profits are higher under Bertrand competition can increase. Higher outputs under Bertrand competition compared to Cournot competition generate higher R&D investments under the former than the latter, which is responsible for our result.

Since both outputs and R&D investments are higher under Bertrand competition, we get higher consumer surplus and welfare under Bertrand competition compared to Cournot competition.

There is a literature comparing Bertrand-Cournot competition under a two-stage strategic commitment R&D. While Qiu (1997) and Bonanno and Haworth (1998) consider deterministic process innovation, Delbono and Denicolò (1990), Reynolds and Isaac (1992) and Mukherjee (2011) consider stochastic process innovation. Symeonidis (2003) considers a two-stage strategic commitment product innovation. Unlike our paper, none of these papers show Bertrand-Cournot profit reversal.[3]

Our paper complements Qiu (1997), which considers a structure similar to ours but with strategic commitment R&D. In contrast to Qiu (1997), we find that the R&D investments are higher under Bertrand competition, and the profits are higher under Bertrand competition if the products are sufficiently differentiated and there is positive knowledge spillover. Our result on welfare is also different from that paper. He finds that welfare can be higher under Cournot competition, while welfare in our paper is always higher under Bertrand competition.

Hence, our paper along with Qiu (1997) shows that whether the R&D process provides a strategic commitment effect or not plays an important role for Bertrand-Cournot comparison. Thus, our analysis shows that the consideration of a strategic commitment R&D in the existing literature is not an innocuous assumption.

Although the R&D process with strategic commitment is widely used in the literature, there is scepticism about the strategic commitment effects of R&D investments. As Vives (2008, p. 422) mentioned, "… even though R&D investment typically precedes market interaction, this does not mean that it can be used strategically. That is, it does not follow that R&D investment, or contracts with managers that reward effort, are observable and that firms can commit to it. The evidence on the strategic commitment value of R&D is scant."

Empirical evidence shows that often firms cannot observe R&D projects or R&D investments of the rivals. For example, Cohen (Cohen, 1995, footnote 30, pp. 156) mentions that "… Having asked their respondents (R&D lab managers and directors) at what stage in the innovation process did they first learn of a major R&D project of a rival, only 15% of over 1000

[1]Non-commitment process innovation in our paper considers a situation where firms determine R&D investments and product market variables (outputs or prices) simultaneously. This is different from the two-stage process where R&D investments are determined before product market decisions.

[2]For evidences of knowledge spillover, one may refer to Jaffe (1986), Levin et al. (1987) and Jaffe and Stavins (1994).

[3]There is a literature examining whether more firms are better for welfare. See, Chao et al. (2017) for a recent paper on this topic.

respondents indicated that they were aware of the project at project inception or during the research stage, and 85% reported that they did not learn of the project until either the development stage, or subsequent to product introduction, ... The implication is that firms tend to learn what their rivals are doing rather late in the game, calling into question assumptions about the timeliness of firms' awareness of rivals' R&D activities." Koh and Reeb (2015) show that R&D expenditure data of many innovating firms are not available. Firms may also prefer secrecy than patenting (see, e.g., Cohen et al., 2002, and Hall et al., 2013).

Our purpose in this paper is not to examine the strategic incentive for information disclosure.[4] Rather we show how the R&D investments and product market decisions are determined when information about the rival's R&D investments are not available when product market decisions are taken.

There are also problems of information transmission between the R&D division and the production division of a firm. In an earlier work, Vasconcellos (1994) showed a number of barriers between R&D and production divisions. Interviewing Brazilian companies, that paper showed that "The communication system between Production and R&D is not efficient" is the top barrier (48%) between R&D and production, and this reason is followed by "Production cannot stop to test new processes and products" (47%) and "Production is routine oriented, and resistant to innovation" (34%), as other two top barriers. Ettlie and Stoll (1990) and Vandevelde and Dierdonck (2003) showed the importance of design-manufacturing integration.

Cheng et al. (2015) discussed how globalisation of production and R&D create further challenges to integrate these activities in an efficient way. Instead of giving control solely to the local managers, they suggest to use specific persons who can orchestrate the entire globalisation process, such as developing R&D and production facilities and transferring these activities between sites.

Our goal is not to model the above-mentioned information transmission problem. Rather we assume that due to the problem of information transmission, a firm does not know its post-innovation cost when determining the product market variables. Hence, one may consider that each firm's cost function in our analysis represents a reduced form function that takes into account the coordination issue and each firm's objective is to determine the R&D investments and product market variables simultaneously in the presence of the coordination issue.

The observability issue mentioned above may be pronounced and a non-commitment R&D process considered in this paper maybe more applicable in industries where the time-lag between R&D activities and production is short. For example, many consumer electronics devices have new models introduced annually or even semi-annually. Hence, in the industries with very frequent innovations, R&D activities and production can be considered to happen almost simultaneously from a practical business perspective, as the production division may not have enough time to know about the R&D activities before the product market decision. The scepticism about the strategic commitment effects of R&D investments provides the motivation for considering the effects of a non-commitment process innovation, which is used by Vives (2008, 2020), López and Vives (2019) and Denicolò and Polo (2021) in other contexts. To the best of our knowledge, this is the first paper considering non-commitment process innovation in Bertrand-Cournot comparison.

[4]See, for example, Gal-Or (1986) for strategic information disclosure in oligopoly.

The remainder of the paper is organised as follows. Section 2 describes the model and shows the equilibrium values. Section 3 shows the results. Section 4 concludes. Some mathematical details are relegated to the Appendix.

2 | THE MODEL AND THE EQUILIBRIUM VALUES

Assume that $n(\geq 2)$ symmetric firms are competing in the product market and investing in process innovation. We assume that the firms choose R&D investments and the product market decisions (outputs under Cournot competition and prices under Bertrand competition) at the same time to maximise their own profits. Assume that each firm has the initial marginal cost c and if the ith firm invests r_i in R&D, it reduces its marginal cost to $C_i = \left(c - r_i - \rho \sum_{\substack{j=1 \\ i \neq j}}^{n} r_j\right)$, $i = 1,2,\ldots,n$, where r_i and r_j are the R&D investments of the ith and the jth firms respectively, and $\rho \in [0,1]$ shows the percentage of knowledge spillover. There is no knowledge spillover for $\rho = 0$ and knowledge spillover is complete for $\rho = 1$. For each firm, the cost of investing r amount in R&D is τr^2, where τ is the inverse of the efficiency or productivity of the R&D technology.

Since the firms are determining R&D investments and product market variables at the same time, a firm does not know the rival's R&D investment when taking its production decision but it is aware that the rival's R&D will create ρ percentage of knowledge spillover. Hence, a firm understands that its cost will reduce by ρr if the rival investments r amount in R&D but it does not know the exact value of ρr at the time of output determination due to the lack of information about r.

We will do our analysis under the following assumption:

A1: $\tau > \frac{n}{4c}$.[5]

A1 will ensure that the equilibrium outputs, prices, R&D investments, and the marginal costs ex-post R&D are positive at the interior solutions.

Assume that the utility function of the representative consumer is

$$U = \sum_{i=1}^{n} q_i - \frac{1}{2}\left(\sum_{i=1}^{n} {q_i}^2 + 2\gamma \sum_{i \neq j} q_i q_j\right) \tag{1}$$

where q_i and q_j are the outputs of the ith and the jth firms respectively, $i,j = 1, 2, \ldots, n$, $i \neq j$. The parameter $\gamma \in [0,1]$ measures the degree of product differentiation. If $\gamma = 1$, the products are perfect substitutes and if $\gamma = 0$, the products are isolated. To avoid the well-known Bertrand paradox and to consider competition between the firms, we restrict our attention to $\gamma \in (0,1)$.

The utility function (1) gives the ith firm's inverse market demand function as:

[5] In terms of our parameters, the related assumption in Qiu (1997) is $\tau > \frac{1}{c}$.

$$P_i = 1 - q_i - \gamma \sum_{i \neq j} q_j, \mathrm{i} = 1, 2, \ldots, \mathrm{n}, \mathrm{i} \neq \mathrm{j}$$

The corresponding demand function for the ith firm is:

$$q_i = \frac{1 - \gamma - P_i(1 + (n-2)\gamma) + \gamma \sum_{i \neq j} P_j}{(1-\gamma)(1 + (n-1)\gamma)}, i, j = 1, 2, \ldots, n, i \neq j$$

We assume $c < 1$.

2.1 | Cournot competition

Under Cournot competition, the ith firm chooses its output and the R&D investment to maximize $\pi_i = (P_i - C_i)q_i - \tau r_i^2$, $i = 1, 2, \ldots, n$.

The symmetric equilibrium outputs and the R&D investments are:

$$q_1^C = q_2^C = \ldots = q_n^C = q^C = \frac{2(1-c)\tau}{\Omega} > 0 \quad (2)$$

$$r_1^C = r_2^C = \ldots = r_n^C = r^C = \frac{(1-c)}{\Omega} > 0, \quad (3)$$

where $\Omega = 4\tau - 1 - \rho(n-1) + 2\gamma\tau(n-1) > 0$.

Assumption **A1** ensures that the equilibrium values are positive, the second order conditions hold and $C_i^C = (c - r^C - \rho(n-1)r^C) > 0$.

Higher knowledge spillover increases the outputs by reducing the costs of production. Since higher outputs increase the R&D investments (see the first order condition $\frac{\partial \pi_i}{\partial r_i} = 0$ in Appendix A), higher knowledge spillover increases the R&D investments by increasing the outputs.

The equilibrium profit of the ith firm is

$$\pi_1^C = \pi_2^C = \ldots = \pi_n^C = \pi^C = \frac{(1-c)^2\tau(4\tau-1)}{\Omega^2} > 0. \quad (4)$$

2.2 | Bertrand competition

Under Bertrand competition, the ith firm chooses its price and R&D investment to maximize $\pi_i = (P_i - C_i)q_i - \tau r_i^2$, $i = 1, 2, \ldots, n$.

The symmetric equilibrium prices, outputs and the R&D investments are:

$$P_1^B = P_2^B = \ldots = P_n^B = P^B = \frac{\begin{array}{c}2(1+c-\gamma+c(n-2)\gamma)(1+(n-1)\gamma)\tau \\ -(1+(n-2)\gamma)(1+(n-1)\rho)\end{array}}{\Psi} > 0 \quad (5)$$

$$q_1^B = q_2^B = \ldots = q_n^B = q^B = \frac{2(1-c)(1+(n-2)\gamma)\tau}{\Psi} > 0 \quad (6)$$

$$r_1^B = r_2^B = \ldots = r_n^B = r^B = \frac{(1-c)(1+(n-2)\gamma)}{\Psi} > 0, \quad (7)$$

where $\Psi = 2\,(2 + (n - 3)\gamma)\,(1 + (n - 1)\gamma)\tau - (1 + (n - 2)\gamma)\,(1 + (n - 1)\rho) > 0$.

It can be found that the second-order conditions for profit maximization hold for $\gamma \in (0,\gamma^*)$, where $\gamma^* = \frac{2-n-8\tau+4n\tau}{8(n-1)\tau} + \frac{1}{8}\sqrt{\frac{4-4n+n^2-16\tau+16n\tau-8n^2\tau+16n^2\tau^2}{(n-1)^2\tau^2}}$

(See Appendix B). Hence, the above-mentioned equilibrium values hold under **A2**. Since we will focus on the interior solutions, we will assume in the following analysis:

A2: $\gamma \in (0,\gamma^*)$.

Further, assumption **A1** ensures $C_i^B = (c - r^B - \rho(n-1)r^B) > 0$.

Like Cournot competition, higher knowledge spillover increases the outputs and R&D investments under Bertrand competition.

The equilibrium profit of the ith firm under assumption **A2** is

$$\pi_1^B = \pi_2^B = \ldots = \pi_n^B = \pi^B = \frac{\begin{array}{c}(1-c)^2(1+(n-2)\gamma)\tau \\ (4(1-\gamma)(1+(n-1)\gamma)\tau-(1+(n-2)\gamma))\end{array}}{\Psi^2} > 0. \quad (8)$$

3 | COMPARING COURNOT AND BERTRAND

First, compare the equilibrium outputs and R&D investments, since these are the main ingredients for our main result of Bertrand-Cournot profit reversal.

Proposition 1. *Assume **A1** and **A2**. The R&D investments and outputs are higher under Bertrand competition compared to Cournot competition.*

Proof. See Appendix C.■

Intense competition under Bertrand competition compared to Cournot competition creates higher outputs under the former than the latter. Higher outputs under Bertrand competition creates higher R&D investments under Bertrand competition compared to Cournot competition, thus providing a different ranking of R&D investments from Qiu (1997).

In Qiu (1997), commitment to the R&D investment by a firm creates a strategic effect on the competitor's choice. Under Cournot competition, the strategic effect creates the incentive for committing to a higher R&D investment to reduce the output of the competitor. Under Bertrand competition, the strategic effect creates the incentive for committing to a lower R&D investment to encourage the competitor to charge a higher price. These strategic effects create higher R&D investments under Cournot competition compared to Bertrand competition.

The non-commitment R&D in our analysis does not create these commitment effects. In our analysis, the higher output under Bertrand competition induces the firms to invest more in R&D under Bertrand competition compared to Cournot competition.

Due to the complicated profit expressions, we first show our main result of Bertrand-Cournot profit reversal with $n = 2$. We then use an example to show that our result holds for $n \geq 2$.

If $n = 2$, we get $\pi^C = \frac{(1-c)^2\tau(4\tau-1)}{(2(2+\gamma)\tau-1-\rho)^2}$, $\pi^B = \frac{(1-c)^2\tau(4(1-\gamma^2)\tau-1)}{(2(2-\gamma)(1+\gamma)\tau-1-\rho)^2}$, and

$$\pi^C - \pi^B = \frac{4(1-c)^2\gamma^2\tau^2(\rho+\rho^2-2\gamma\tau-\gamma^2\tau-4\rho\tau-4\gamma\rho\tau+8\gamma\tau^2+8\gamma^2\tau^2)}{(-1-\rho+4\tau+2\gamma\tau)^2(1+\rho-4\tau-2\gamma\tau+2\gamma^2\tau)^2} < (>)0$$

for $\gamma \in (0, \gamma^{**})$ $(\gamma \in (\gamma^{**}, \gamma^*))$ if $\rho \in (0, 1]$, where $\gamma^{**} = \frac{1+2\rho-4\tau}{-1+8\tau} + \sqrt{\frac{\rho+\rho^2+\tau-8\rho\tau-4\rho^2\tau-8\tau^2+16\rho\tau^2+16\tau^3}{\tau(-1+8\tau)^2}}$, $\gamma^{**} < \gamma^*$ and $\gamma^{**} > 0$ for $\rho > 0$.

We get $\frac{\partial\gamma^{**}}{\partial\tau} < 0$ (see Appendix D), implying that as the efficiency of R&D increases (i.e., τ decreases), it increases the range of product differentiation over which the profits are higher under Bertrand competition. This happens since the marginal benefit from a lower τ is more under Bertrand competition compared to Cournot competition, due to a higher output under the former than the latter.

Since the industries differ in terms of c, for example, automobile industry can have a higher c compared to pharmaceutical industry, our assumption **A1** implies that we need a higher τ in industries with a lower c and can have a relatively lower τ in industries with a higher c. Hence, given **A1**, the range of product differentiation over which the profits are higher under Bertrand competition will be larger in industries with a higher c, thus allowing to have a relatively lower τ.

Since the firms are symmetric, we get the following result from the above discussion.

Proposition 2. *Consider $n = 2$ and assume **A1** and **A2**. If $\rho \in (0,1]$, the profit of each firm and the total profits of the firms are higher under Bertrand (Cournot) competition for $\gamma \in (0,\gamma^{**})$ $(\gamma \in (\gamma^{**}, \gamma^*))$. Further, we get $\frac{\partial\gamma^{**}}{\partial\tau} < 0$, that is, the range of γ over which the profits are higher under Bertrand competition increases with a lower τ.*

There are two effects. First, higher intensity of competition under Bertrand competition compared to Cournot competition tends to create lower profits under the former than the latter. Second, higher R&D investments under Bertrand competition compared to Cournot competition make the firms more cost efficient and tend to create higher profits under the former than the latter.

If the products are sufficiently close substitutes, intense competition under Bertrand competition compared to Cournot competition becomes the important factor to create lower profits under the former than the latter. If the products are sufficiently differentiated, the difference in the intensity of competition is not significant. In this situation, higher cost efficiency under Bertrand competition compared to Cournot competition creates higher profits under the former than the latter for positive knowledge spillover, since positive knowledge spillover increases cost efficiency under Bertrand compared to Cournot competition.

Now consider the following example with $\tau = 2$, $\rho = 0.8$, $n \in [2,5]$ and $\gamma \in [0,0.25]$ to see how $\pi^C - \pi^B$ changes with n and γ. We consider the number of firms from 2 to 5 as a continuous variable. We plot $\frac{\pi^C - \pi^B}{(1-c)^2}$ in Figure 1. The shaded (white) region in Figure 1 shows $\frac{\pi^C - \pi^B}{(1-c)^2} < (>)0$ or $\pi_i^C - \pi_i^B < (>)0$.

It follows from Figure 1 that the range of γ over which Bertrand competition creates higher profits increases with higher n. Since more firms help to increase cost efficiency by increasing knowledge spillover, as the number of firms increases, the rage of γ over which Bertrand competition creates higher profits increases.

Proposition 2 showed that the profit reversal can occur in a duopoly for positive spillover. Hence, rather than considering $\rho = 0.8$, one may consider a lower value of knowledge spillover, such as $\rho = 0.1$, to show a result like Figure 1. However, we have considered $\rho = 0.8$ in Figure 1 since its helps to show the effects of a higher n on the threshold values of γ easily. We acknowledge that the combination of very high product differentiation and very high knowledge spillover may not be easily observable in the real life. However, as shown in Proposition 2, the profit reversal occurs as long as there is positive knowledge spillover.

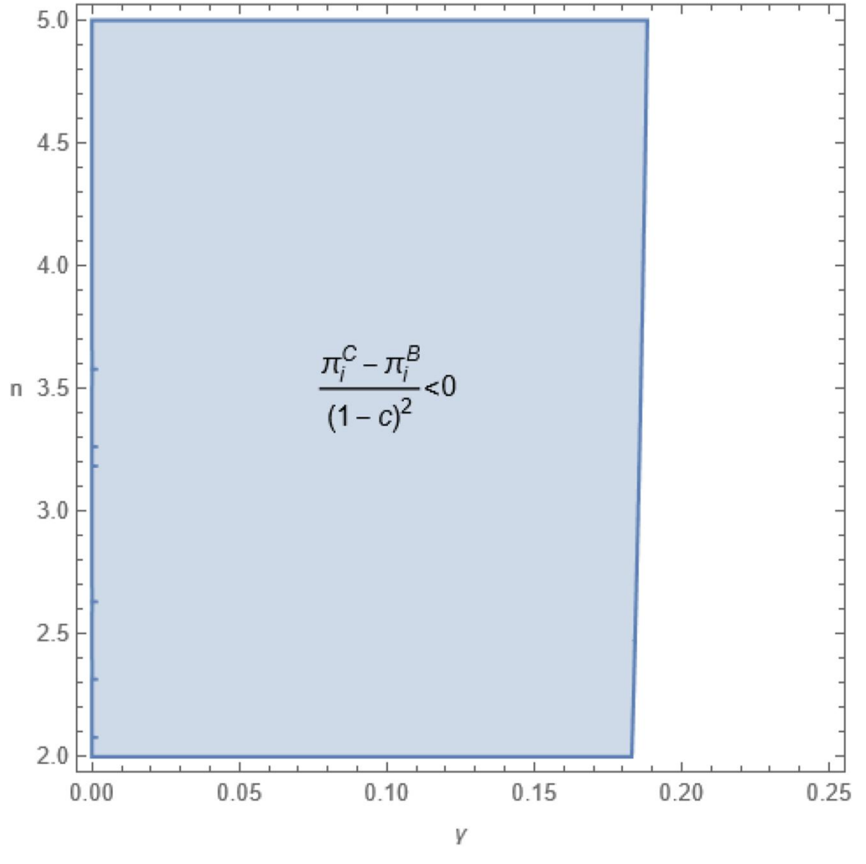

FIGURE 1 $\pi_i^C - \pi_i^B$ for $\tau = 2, \rho = 0.8, n \in [2, 5]$ and $\gamma \in [0, 0.25]$

If we compare consumer surplus and welfare, we will get results similar to the usual belief, that is, consumer surplus and welfare are higher under Bertrand compared to Cournot competition. It follows from Singh and Vives (1984) that if the marginal costs are the same under Cournot and Bertrand competition, consumer surplus and welfare are higher under Bertrand competition compared to Cournot competition. In our analysis, higher R&D investments and therefore, lower marginal costs under Bertrand competition compared to Cournot competition strengthen these results. Hence, our result on welfare implications is different from Qiu (1997). Different rankings of R&D investments under Qiu (1997) and our paper are the reasons for this difference.

4 | CONCLUSION

The main contribution of this paper is to provide a new reason for higher profits under Bertrand competition compared to Cournot competition. We show that the firms get higher profits under Bertrand competition compared to Cournot competition under non-commitment process innovation if the products are sufficiently differentiated and there is positive knowledge spillover. Higher R&D investments under Bertrand competition compared to Cournot competition is the reason for our result.

As a final remark, like the model of Qui (1997), which could be used for firms' marketing investments with spillover effects to increase demand intercepts, our model could also be used for marketing investments to increase demand intercepts.

ACKNOWLEDGEMENTS

We would like to thank two anonymous referees of this journal for helpful comments and suggestions. Qidi Zhang gratefully acknowledges the financial support from Shandong Province Social Science Planning and Research Special Project under the grant number 23CCXJ11. The usual disclaimer applies.

CONFLICT OF INTEREST STATEMENT

None.

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How to cite this article: Zhang, Q., Wang, L. F. S., & Mukherjee, A. (2024). Bertrand-Cournot profit reversal under non-commitment process innovation. *The Manchester School*, 1–12. https://doi.org/10.1111/manc.12471

APPENDIX A: FIRST ORDER CONDITIONS OF MAXIMISATION UNDER COURNOT COMPETITION

We get

$$\frac{\partial \pi_i}{\partial q_i} = P_i - C_i - q_i = 0$$

$$\frac{\partial \pi_i}{\partial r_i} = q_i - 2\tau r_i = 0$$

APPENDIX B: SECOND ORDER CONDITION UNDER BERTRAND COMPETITION

The first order conditions of profit maximisation for the *i*th firm are

$$\frac{\partial \pi_i}{\partial p_i} = q_i - \frac{(P_i - C_i)(1 + \gamma(n-2))}{(1-\gamma)(1+\gamma(n-1))} = 0$$

$$\frac{\partial \pi_i}{\partial r_i} = q_i - 2\tau r_i = 0$$

We get $\frac{\partial^2 \pi_i}{\partial {P_i}^2} < 0$, $\frac{\partial^2 \pi_i}{\partial {r_i}^2} < 0$ and the Hessain matrix for the *i*th firm is positive, that is,

$$H_i = \begin{bmatrix} \frac{\partial^2 \pi_i}{\partial P_i^2} & \frac{\partial^2 \pi_i}{\partial P_i \, \partial r_i} \\ \frac{\partial^2 \pi_i}{\partial r_i \, \partial P_i} & \frac{\partial^2 \pi_i}{\partial r_i^2} \end{bmatrix} = \begin{bmatrix} \frac{2 + 2(-2+n)\gamma}{(-1+\gamma)(1+(-1+n)\gamma)} & \frac{1 + (-2+n)\gamma}{(-1+\gamma)(1+(-1+n)\gamma)} \\ \frac{1 + (-2+n)\gamma}{(-1+\gamma)(1+(-1+n)\gamma)} & -2\tau \end{bmatrix} > 0$$

for $\gamma \in (0, \gamma^*)$, where

$$\gamma^* = \frac{2 - n - 8\tau + 4n\tau}{8(-1+n)\tau} + \frac{1}{8}\sqrt{\frac{4 - 4n + n^2 - 16\tau + 16n\tau - 8n^2\tau + 16n^2\tau^2}{(-1+n)^2\tau^2}}$$

APPENDIX C: PROOF OF PROPOSITION 1

We get $q^C - q^B = \frac{-4(1-c)(n-1)\gamma^2\tau^2}{\Omega\Psi} < 0$ and $r^C - r^B = \frac{-2(1-c)(n-1)\gamma^2\tau}{\Omega\Psi} < 0$ under **A1** and **A2**.

APPENDIX D: $\frac{\partial\gamma^{**}}{\partial\tau} < 0$

We get

$$\frac{\partial\gamma^{**}}{\partial\tau} = \frac{4}{1-8\tau} + \frac{8(-1-2\rho+4\tau)}{(1-8\tau)^2} + \frac{\begin{array}{c}\rho(1+\rho)-24\rho(1+\rho)\tau\\ +8(-1+2\rho(7+4\rho))\tau^2+32(1-4\rho)\tau^3\end{array}}{2\tau^2(-1+8\tau)^3\sqrt{-\frac{(-1+4\tau)(\rho+\rho^2+\tau-4\rho\tau-4\tau^2)}{(1-8\tau)^2\tau}}}$$

which can be shown negative under **A1**.