# Innovation and Market Structure in Presence of Spillover Effects

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## Abstract

The paper proposes a theory of innovation-as the fruit of science parks-and market structure. The model incorporates n firms with horizontal spillovers all interacting within a hypothetical industry. In a two stage sequential game framework, four types of cooperation are studied: non-cooperation in both stages, cooperation in both stages, cooperation in R&D stage and non-cooperation in production stage and simultaneous cooperation and non-cooperation in the R&D stage.

The effect of competition on total innovation investment varies among all four cases and mostly depends on the extent of competition, spillover effects and marginal production costs.

## 1. Introduction:

The purpose of this paper is to analyze the relationship between competition and innovation under different coordination scenarios and in the presence of appropriability. Appropriability in the form of horizontal spillovers highlights how the technological environment affects the relationship between competition and innovation. Coordination scenarios are visualized as cooperation and non-cooperation, with and without information sharing and in a two stage game framework. The relationship between competition and innovation in absence of spillovers is clearly predictable. This relationship is of a negative nature since increase in competition absorbs the cost incentives by reducing the price. However, this is not the final version of the story. When the number of firms and competition in a specific market increases, two opposite effects are being triggered simultaneously. The first effect is the negative effect of competition on innovation, something which we have already explained. The second one, with a considerable importance, refers to spillover effect in an aggregate scale. Increase in the number of active firms in the market inflates the total spillover, decreases each firm's marginal production cost and, consequently, boosts the innovation motivation. Which of these two dominates eventually answers the main objective of this paper.

Although this question has been the center of a long time debate, the literature lacks a mathematical explanation to draw a solid line under the final results. Amendola and Gaffard (2003) try to develop this idea by having a simulation analysis. They traced a trade-off between innovation and competition and it showed that frequent innovation helps maintain competition because the former reduces the intervals during which firms may enjoy monopolistic power. They also discussed whether competition could entail a negative unit margin which would induce firms not to innovate. They conclude that the existence of financial constraints is required to coordinate the activity of competing firms as it prevents over-investments as a whole which, in turn, makes it possible to have positive unit margins. In another effort to shed light on the murkier aspects of this discussion, Symeonidis (2001) studies the effect of price competition on innovation, market structure and profitability in R&D intensity.

Pradeep and Chien-wei (2002) use a linear model and consider firms which engage in a Cournot competition over a common product but can undertake innovation, thus improving the quality of their product. They conclude that innovation is discouraged by too much or too little competition and occurs only when the industry is of intermediate size.

Amendola, Garrard and Musso (2000) show that in the presence of an increasing return to scale and a high rate of innovation, competition may obtain due to changes in demand and cost conditions. Their results stay valid in absence of differentiation and homogeneity of the competing firm's products. They develop a theoretical model and confirm their findings by carrying simulation analysis in the case of two firms competing on the market.

The work of Aghion, Bloom, Blundell, Griffith and Howitt might be the most appealing research done in this field. Investigating the relationship between product market competition and innovation, they find an inverted U relationship. Using panel data they support their findings empirically. They also proceed with two additional predictions of the model. First they show that the average technological distance between leaders and followers increases with competition. Second, the inverted U is steeper when industries are more neck and neck. They support these two findings with the data they present in their paper.

The paper is organized as follows. In the second section we study the case of non-cooperation in both stages of the game. Part three concentrates on the case when firms act cooperatively in the first stage but continue non-cooperatively in the proceeding stages. Section four analyzes the case of cooperation in both stages. Part five studies the simultaneous cooperative and non-cooperative activities in the second stage while all firms act non-cooperatively in the first stage. Section six concludes.

## 2. Non-cooperation in both stages:

We assume there are n firms in the market each having the share $m_i$. We also assume that all firms are facing a linear demand function $P = a - bQ$ in which $P$ is the price each firm faces and Q is the total quantity demanded in the market. Each firm undertakes an innovation activity which costs her $\gamma(x_i)$ which has a cost reduction benefit of $x_i$ for her and $\beta_i x_i$ for her rivals (competitors). Each firm has a two period decision platform. In the first period she decides about the level of her R&D investment and in the second stage she will finalize her production decision based on the information obtained in the first stage. Using a backward induction approach, the discussion begins from the second stage. In this stage, as previously stated, the firm decides about her production level, then:

$$\underset{m_i}{Max} \quad \pi_i = (a - bQ) m_i Q - \left( A - x_i - \sum_{j \neq i} \beta_j x_j \right) m_i Q - \frac{x_i^2}{2}$$

And our first order condition is:

$$m_i = \frac{a - \left( A - x_i - \sum_{j \neq i} \beta_j x_j \right) - bQ}{bQ}$$

Knowing that $\sum m_i = 1$ we can calculate Q, then substituting these two back into the profit function will result in the following:

$$\pi_i = \frac{1}{b} \left[ a - \frac{(a - A)n + \sum x_i + (n-1) \sum \beta_i x_i}{n+1} - \left( A - x_i - \sum \beta_j x_j \right)^2 \right] - \frac{x_i^2}{2}$$

Now at the first stage, the decision making firm maximizes her profit, with respect to $x_i$, knowing the optimal value of production from the previous stage thus it can be concluded:

$$\underset{x_i}{Max} \quad \pi_i = \frac{1}{b}\left[ a - \frac{(a-A)n + \sum x_i + (n-1)\sum \beta_i x_i}{n+1} - \left( A - x_i - \sum \beta_j x_j \right)^2 \right] - \frac{x_i^2}{2}$$

The first order condition will be:

$$\frac{1}{b}\left[ -\frac{(n-1)\beta_i + 1}{n+1} + 2\left( A - x_i - \sum \beta_j x_j \right) \right] - x_i = 0$$

This provides us with the notion of optimum innovation investment for firm i. Since we are interested in the total innovation investment in this hypothetical economy and appeal to symmetry, the equation is:

$$X = nx = \frac{n(2A(n+1) - n\beta + \beta - 1)}{(n+1)(2 + b + 2(n+1)\beta)}$$

To find out what would be the marginal effect of increase in the number of firms on the innovation we must use the following:

$$\frac{\partial X}{\partial n} = \frac{\left(b - 2A(n+1)^2 (2 + b - 2\beta) + b(n(n+2) - 1)\beta + 2(1 + (n-1)\beta)^2\right)}{\left((n+1)^2 (2 + b + 2(n-1)\beta)^2\right)}$$

We can also graph the change in total innovation when the number of firms and level of spillover changes, thus:

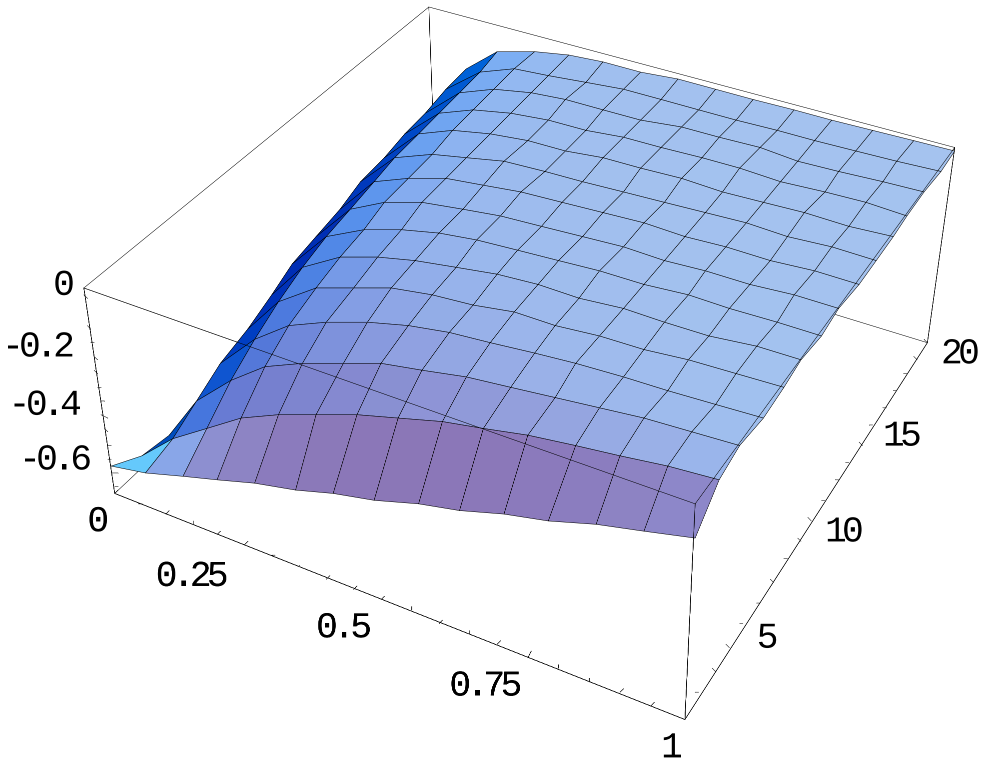


**Figure (1) - Competition and innovation (non-cooperation case)**

As seen in Figure (1), competition affects innovation positively regardless of the level of appropriability. The interesting fact here is that increase in the level of spill-over reduces the intensity of the positive relation.

***Proposition 1:*** In the event of non-cooperation in both stages, increase in competition inflates the total innovation outcome.

## 3. Cooperation in R&D and information sharing:

This refers to a case similar to the previous one but this time firms share their innovation information in an exchange program. In this case the second stage stays non-cooperative but in the first stage firms maximize the joint profits which results in:

$$\underset{x_i}{Max} \quad \sum \pi_i = \pi_1 + \pi_2 + .... + \pi_n$$

or:

$$\underset{x_i}{Max} \quad \sum \pi_i = \sum \left( \frac{1}{b} \left[ a - \frac{(a-A)n + \sum x_i + (n-1)\sum \beta_i x_i}{n+1} - \left( A - x_i - \sum \beta_j x_j \right) \right]^2 - \frac{x_i^2}{2} \right)$$

The first order condition is:

$$\frac{1}{b}\left[ -\frac{n(n-1)\beta_i + n}{n+1} + 2\left( A - x_i - \sum \beta_j x_j \right) \right] - x_i = 0$$

Using the notion of symmetry we have:

$$x = \frac{2A(n+1) + n(\beta - n\beta - 1)}{(n+1)(2+b+2\beta)}$$

Summing over the x will result:

$$X = nx = \frac{n(2A(n+1) + n(\beta - n\beta - 1))}{(n+1)(2+b+2\beta)}$$

And differentiating with respect to n:

$$\frac{\partial X}{\partial n} = \frac{\left(-2A(n+1)^2 + n\left(2 + n + 2\left(n^2 + n - 1\right)\beta\right)\right)}{\left((n+1)^2 (2+b+2\beta)\right)}$$

In this case the effect of competition on innovation depends on the value of A or the marginal cost and number of firms as well as the spillover effects. In fact the competition effect on innovation is positive if we have the following:

$$\frac{\left(n\left(2 + n + 2\left(n^2 + n - 1\right)\beta\right)\right)}{2(n+1)^2} > A$$

Graphing above expression when the level of spillover and number of changes vary:

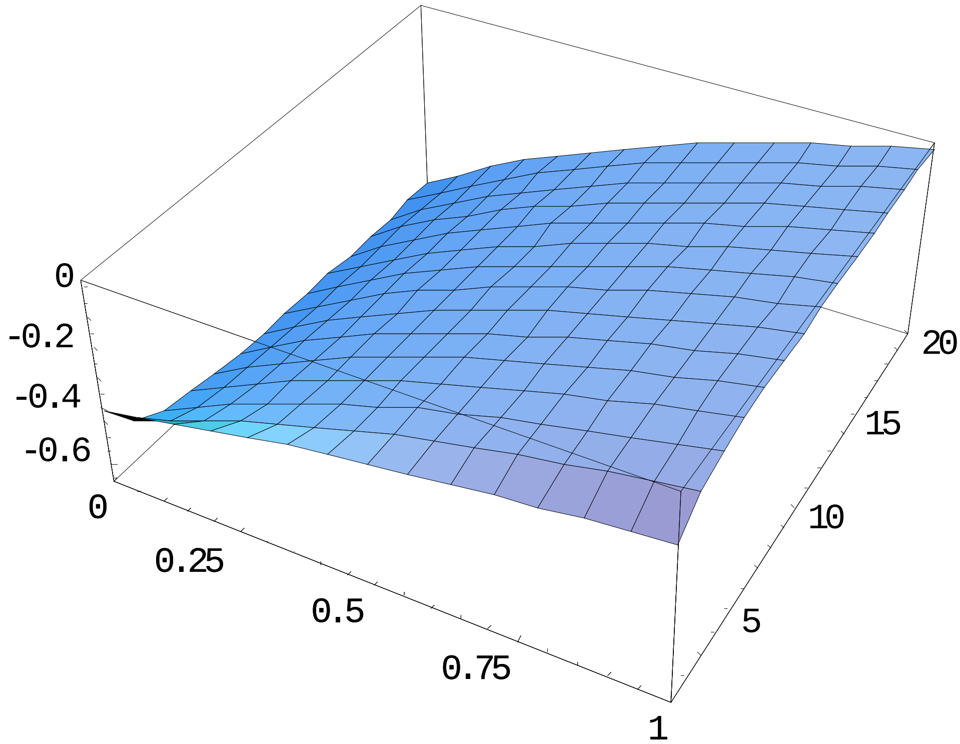


**Figure (2)-Competition and Innovation (non-cooperation in the production stage and cooperation in R&D stage case)**

If firms cooperate only in their R&D, the effect of innovation on competition depends on the number of firms, the level of spillovers and the marginal cost of production. Having a reasonable assumption about the value of the marginal cost of production, when level of spillover and number of participating firms are low, the competition tends to show a negative influence on innovation. This relationship is positive in presence of high spillovers while still having a low number of participating firms.
When information about innovation is completely being disclosed between rivals we have:

$$\frac{\partial X}{\partial n} = \frac{\left(-2A(n+1)^2 + n\left(2+n+2(n-1)^2\right)\right)}{\left((n+1)^2(b+4)\right)}$$

And this expression is positive if:

$$\left(-2A(n+1)^2 + n^2(2n+3)\right) > 0 \Rightarrow \frac{n^2(2n+3)}{2(n+1)^2} > A$$

Assuming $A = 1$ we can simply sign the above equation and come to the conclusion that this expression is always positive. In fact signing this non-equality would result in the following:

$$if \qquad n \in \left(-0.5\ ,\sqrt{2}\right) \Rightarrow \frac{\partial X}{\partial n} < 0$$

$$if \qquad n \in \left(\sqrt{2}\ ,+\infty\right) \Rightarrow \frac{\partial X}{\partial n} > 0$$

Since in the oligopoly market $n$ is always bigger than one, the sign of the above expression is always positive meaning an increase in competition, when the R&D outcome is being shared transparently between firms, increases the total innovation.

***Proposition 2:*** In the event of cooperation in R&D, when the level of spillover and the number of participating firms are low, the competition tends to show a negative influence on the innovation. However, this relationship is positive in the presence of high spillovers.

## 4. Cooperation in both stages:

In this case firms behave cooperatively in both stages of their operation, with the innovation as the first stage and production as the second. Having the same set of assumptions, the objective in the first stage would be the level of production which maximizes the total profit, meaning:

$$\underset{Q}{Max} \quad \pi_i = (a - bQ)Q - \left( A - x_i - \sum_{j \neq i} \beta_j x_j \right) Q - \sum \frac{x_i^2}{2}$$

And the first order condition, under the symmetry condition will result in:

$$\frac{\partial \pi}{\partial Q} = 0 \Rightarrow Q = \frac{a - A + \left( (n-1)\beta + 1 \right) x}{2b}$$

Substituting this value into the profit function will result in:

$$\pi = \frac{1}{b} \left[ \frac{(a - A) + \left( (n - 1\beta + 1) x \right)}{2} \right]^2 - \frac{nx^2}{2}$$

Now at the preceding stage the innovation will be the objective, we have:

$$x = \frac{(a - A)\left( (n-1)\beta + 1 \right)}{2n - \left( (n-1)\beta + 1 \right)^2}$$

And then for all firms:

$$nx = \frac{(a - A)\left( (n^2 - n)\beta + n \right)}{2n - \left( (n-1)\beta + 1 \right)^2}$$

The increase of the number of firms creates the following effect on innovation:

$$\frac{\partial X}{\partial n} = \frac{(a - A)\left( -1 + \left( 3 - 2n + 2n^2 \right)\beta - \left( 3 - 4n + n^2 \right)\beta^2 + (n-1)^2 \beta^3 \right)}{\left( 2n - \left( (n-1)\beta + 1 \right)^2 \right)^2}$$

We can also use the same simulation method to discuss the sign of the above expression:

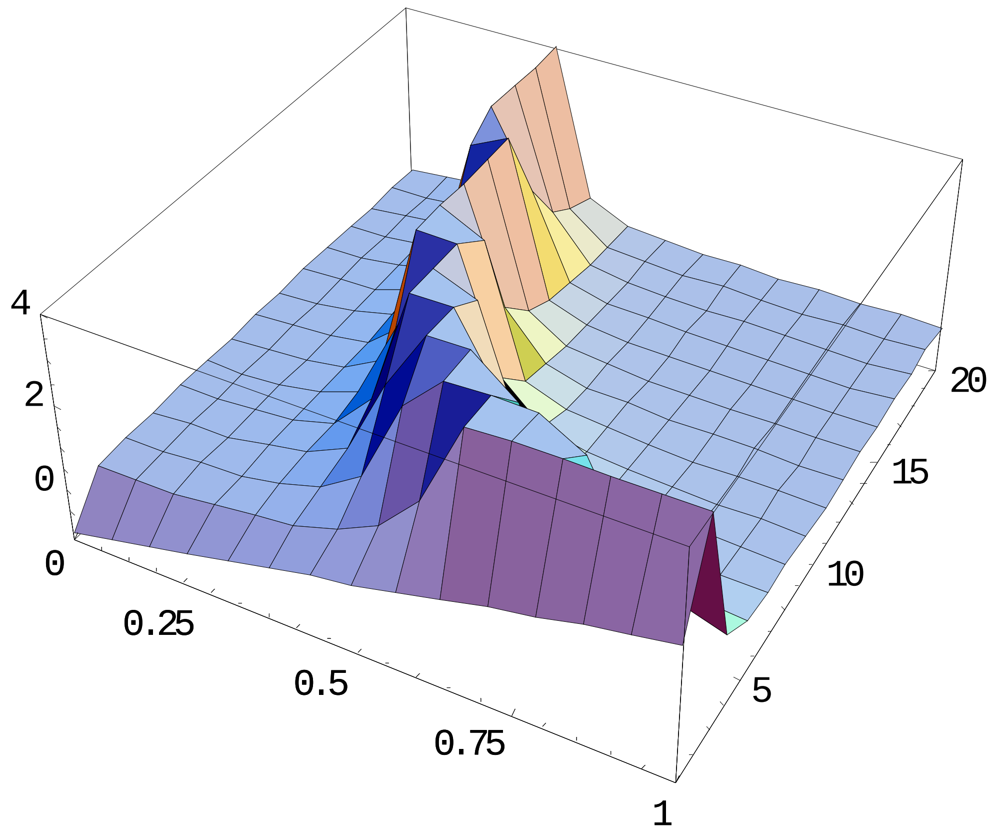


**Figure (3)-Competition and Innovation (the case of cooperation in both stages)**

As we see, the effect competition has on innovation is directly dependant on the level of spillover and the number of firms. For very low levels of spillover, as the number of firms increases total innovation increases smoothly. As the level of spillover increases, raise in the number of firms initiates an increasingly positive effect on innovation which, after reaching its maximum, turns to a negative relationship. Consequently, increase in the level of spillover reduces the maturity threshold.

In case of information sharing **(** $\beta = 1$**),** we would have:

$$\frac{\partial X}{\partial n} = \frac{2n^2(a-A)}{(2n-n^2)^2} > 0$$

As we can see above, the expression is always positive meaning competition increases innovation as long as the firms cooperate in both production and innovation processes and the innovation information is completely transparent.

***Proposition 3:*** In the event of cooperation in both stages, the effect of competition on innovation depends on the level of spillover and the number of firms. As the level of spillover increases, a raise in the number of firms initiates an increasingly positive effect on innovation which, after reaching its maximum, turns to a negative relationship. .

## 5. Simultaneous cooperation and non-cooperation in the innovation stage:

In this case we assume that firms act non-cooperatively in the first stage or the production stage while, simultaneously, a sub-group of firms cooperate with each other.

Our first stage results stay the same as our first case but for the second stage, we assume that $m$ firms cooperate in their innovation and the rest of $n-m=r$ firms keep their non-cooperation status. Our first order condition for non-cooperative firms is:

$$\frac{1}{b}\left(-\frac{(r-1)\beta+1}{r+1}+2\left(A-\left(1+(r-1)\beta\right)x_n-m\beta\,x_c\right)\right)-x_n=0$$

And for cooperative firms is:

$$\frac{1}{b}\left(-\frac{m(m-1)\beta+m}{m+1}+2\left(A-\left(1+(m-1)\beta\right)x_c-r\beta x_n\right)\right)-x_c=0$$

Solving these two expressions simultaneously:

$$x_n=\frac{\left(2A(2+b-2\beta)(m+1)(r+1)+b(m+1)(\beta(1-r)-1)+2(\beta(m-1)+1)\left(\beta\left(m^2+m+1+((m-1)m)-1\right)r\right)-m-1\right)}{\left((2+b-2\beta)(m+1)(r+1)(b+2(1+\beta(m+r-1)))\right)}$$

$$x_c=\frac{\left(2\beta(1+\beta(r-1))r+2A(2+b-2\beta)(m+1)(r+1)-\beta m^2(2+b+2\beta(r-1))(r+1)+m(b(\beta-1)(r+1)+2(1+\beta(r-1))(\beta-1-r+2\beta r))\right)}{\left((2+b-2\beta)(m+1)(r+1)(b+2(1+\beta(m+r-1)))\right)}$$

And total innovation is:

$$X_n=(r+1)x_n=\frac{(r+1)\left(2A(2+b-2\beta)(m+1)(r+1)+b(m+1)(\beta(1-r)-1)+2(\beta(m-1)+1)\left(\beta\left(m^2+m+1+((m-1)m)-1\right)r\right)-m-1\right)}{\left((2+b-2\beta)(m+1)(r+1)(b+2(1+\beta(m+r-1)))\right)}$$

$$X_c=mx_c=\frac{m\left(2\beta(1+\beta(r-1))r+2A(2+b-2\beta)(m+1)(r+1)-\beta m^2(2+b+2\beta(r-1))(r+1)+m(b(\beta-1)(r+1)+2(1+\beta(r-1))(\beta-1-r+2\beta r))\right)}{\left((2+b-2\beta)(m+1)(r+1)(b+2(1+\beta(m+r-1)))\right)}$$

Differentiating the first expression with respect to r provides us with the effect of one more entry to the non-cooperative section of the market which is equal to:

$$\frac{\partial X_n}{\partial r}=\frac{\left(2A(2+b-2\beta)(2+b+2\beta(m-2))(m+1)+\beta\left(-b^2(m+1)\right)+4(1+\beta m(m-1))(m+\beta(m(m-3))-1)+2b(m(m-1)+\beta(m(m(m-3)+1))-1)\right)}{\left((2+b-2\beta)(m+1)(b+2(1+\beta(m+r-1)))^2\right)}$$

Using the simulation technique we have:

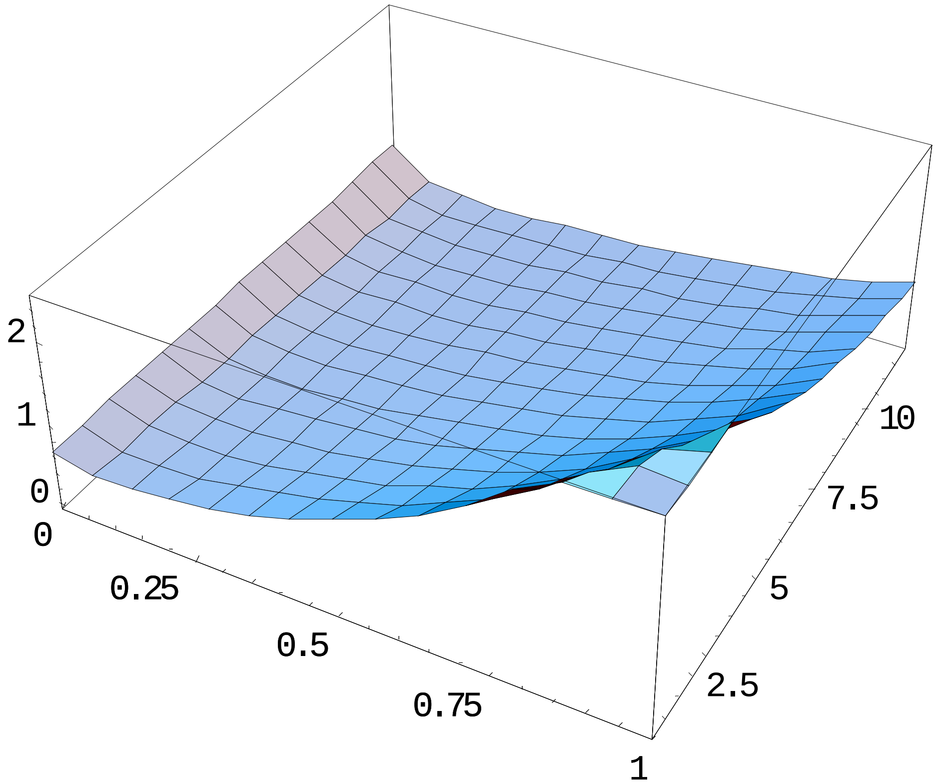


**Figure (4)-Competition and Innovation (Simultaneous cooperation and non-cooperation in R&D stage)**

Our results indicate that competition among non-cooperative firms negatively affect total innovation. In other words, increase in competition among non-cooperative firms reduces market wide innovation. Differentiating the second expression with respect to $m$ provides us with the effect of one more entry to the cooperative section of the market and is equal to:

$$\frac{\partial X_c}{\partial m} = \frac{(2+b+2\beta(r-1))[4m-2A(2+b-2\beta)(m+1)^2(r+1)+bm(2+m+2\beta(m^2+m-1))(r+1)+2(m(m+(m+2)r)+}{(2+b-2\beta)(m+1)^2(r+1)(b+2(1+\beta(m+r-1))^2)}$$
$$\frac{\beta^2(m(m-1)^2(m+2)+r+m(2+m^2(m+2))r+(m(2m^2+m-4)-1)r^2)+\beta(m(m+2)(r(r-2)+2m(r+1)-2)-r))]}{(2+b-2\beta)(m+1)^2(r+1)(b+2(1+\beta(m+r-1))^2)}$$

Using the same technique we have:

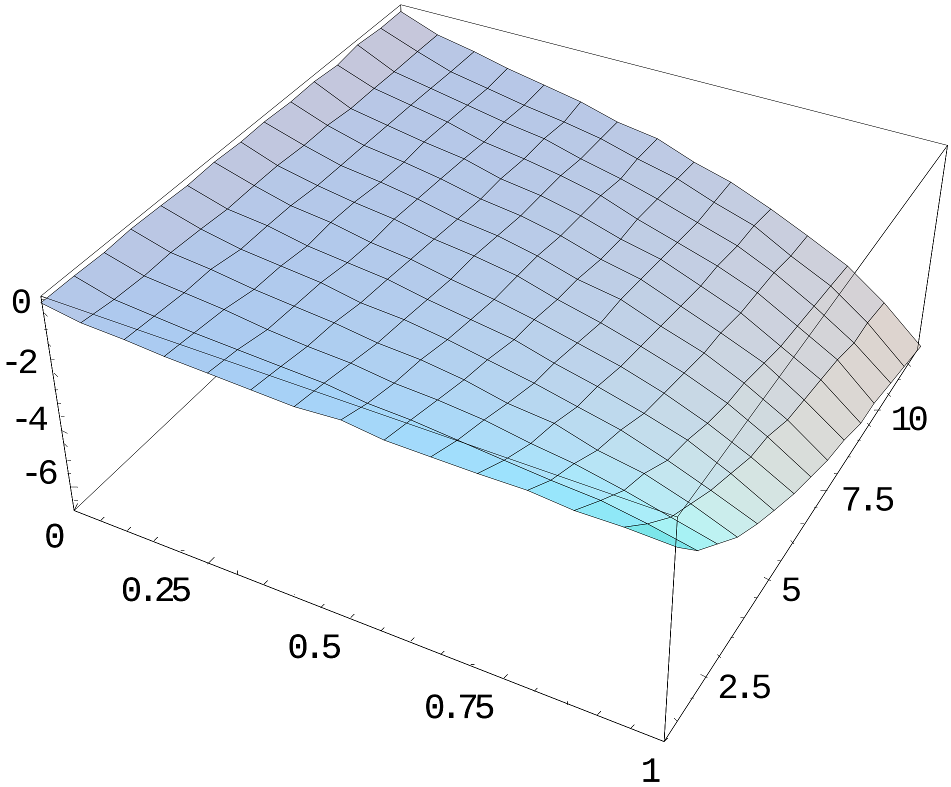


**Figure (5)-Competition and Innovation (Simultaneous cooperation and non-Cooperation in R&D stage-competition among cooperative firms)**

As seen in Figure (5) increase in competition among cooperative firms, reduces the total innovation outcome in the market.

***Proposition 4:*** In the event of simultaneous cooperation and non-cooperation, the increase in competition both among cooperative and non-cooperative firms decreases market wide innovation.

## 6. Conclusion:

Using a two stage game model, effect of competition on innovation under different coordination regimes was studied. In general we showed that the levels of spillover as well as the extent of competition are major factors in this relationship. When firms interact non-cooperatively in both stages, the increase in competition increases the total innovation outcome. Under a full cooperative regime, the extent of competition influence on innovation depends primarily on the scale of spillovers. A bell shape relationship is recognized in the outcome between competition and total innovation, where the skewness is affected by the extent of spillovers. Firms can cooperate only in R&D. Under this scenario, the extent of competition influence on innovation is defined, primarily, by the level of spillovers. When the level of spillovers is low, competition has a negative effect on total innovation. This relationship will be opposite when spillover scope increases.

We also showed that with simultaneous cooperation and non-cooperation in R&D, increase in competition, both among cooperative and non-cooperative firms, will decrease the total level of innovation.

Exclusive to above cases, we discussed the special case of information sharing where applicable. This study is only about creating a primary baseline for future works. The most appealing results for this model are achievable when a non-specific and non-linear demand function replaces our linear example. The sequential game approach could well be replaced by a simultaneous game framework where firms simultaneously decide about their production and R&D investments.

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