Competition & Growth: The Key Role of R&D Duplication Behind the Inverted U

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It is common wisdom that in a static setting, increased rivalry among firms is beneficial to consumers. What is not as obvious is that an increase in competition may be beneficial in a dynamic setting, at least, up to a particular threshold. Importantly, the beneficial impact of competition may be attributable to a result I label the 'Volume Effect'. This paper presents a theoretical R&D patent race endogenous growth model with firms vying to become the next monopolist. Competitors utilize R&D expenditures in order to increase the probability of winning the race, a process that generates quality improvements and growth. Consumers obtain utility from both the quantity and quality of the good. R&D effort is endogenously determined and importantly, growth is driven by deliberate R&D effort, as opposed to an exogenous innovation process, which is typically the case in vertical innovation R&D-based growth models. Additionally, firms, here, are strictly expected profit maximizers.

Within the macroeconomic-industrial organization, Schumpeterian-based literature, I build upon the vertical innovations-oriented models of Philippe Aghion and Peter Howitt et al. (2002),[1] and Robert Barro and Xavier Sala-i-Martin (2004). My goal is to shed some light on the following eight questions: (1) Does an exogenous increase in competition encourage firms to increase R&D effort, discourage firms, have no effect, or have an ambiguous effect? (2) Is it possible to have increased competition dampen R&D effort at the firm level yet, despite this, have the equilibrium growth rate respond positively to competition? (3) What role might R&D duplication play? (4) Does my model generate an 'inverted U' relationship between competition and growth as found by Philippe Aghion and Peter Howitt

(1992)? (5) If so, given that my model can count the number of firms, is it possible to determine the growth-maximizing amount of competition? (6) Does competition enhance equilibrium lifetime utility, diminish it or have no affect? (7) Is it possible for the growth rate and lifetime utility to respond differently to competition? (8) Finally, is there an optimal amount of competition that maximizes utility?

I. Sketch of the Theoretical Quality Innovations Model

This is a discrete time general equilibrium model. The price level, the wage rate, the expected present value of the firm, etc., are each measured in units of final good output. There are two types of economic agents: consumers and firms. Each household maximizes the present value of lifetime utility, beginning in period zero over its lifetime, which is assumed to be infinite. Consumers' lifetime utility, U, is as follows:

$$U = \sum_{t=1}^{\infty} (\frac{1}{1+\rho})^{t-1} \ln C_t \tag{1}$$

where $0 < \rho < 1$ is a subjective discount parameter, C_t represents the total consumption of the final good in period t consumed by the consumer, and B_{t+1} are the new bonds purchased in period t, maturing in period $t+1$.

There are two types of firms: the final good sector firms; and, the intermediate good sector firms. The former type of firm is assumed to be perfectly competitive while the latter is not. The latter type plays a more important role; intermediate good firms undertake R&D and R&D drives growth. R&D, here, is modeled as demand-enhancing (product innovation), as in models such as Pradeep Dubey and Chien-wei Wu (2001), rather than cost-reducing.

Each final good producer maximizes the present value of all future expected profits each period, which is a function of the quality-adjusted intermediate good, fueled by R&D, and labor input to the final good sector. Production in the final good sector is given by the following equation:

$$Y_t = A_t h_t^a (X_t Q_t)^{1-a} \tag{2}$$

where Y_t is final good output, the parameter A_t is the exogenously-determined measure of total-factor productivity, h_t is labor input to the final good sector, a is the elasticity of the final good with respect to labor input to the final good sector, where I assume $0 < a < 1$. $X_t Q_t$ is the quality-adjusted intermediate good, where X_t is the quantity of the intermediate good in period t, Q_t is the quality degree of the intermediate good in period t, and, $(1-a)$, represents the elasticity of the final good with respect to the quality-adjusted intermediate good. Final good producers choose the amount of labor input to the final good sector and the amount of the quality-adjusted intermediate good, each period. They take the current wage rate and the current degree of intermediate good quality as given.

In the intermediate good sector, each period, a monopolistic winner leapfrogs the previous winner and dominates the market. The only uncertainty is the identity of the winner. There are no fixed or entry costs and firms are symmetric. Importantly, the current quality of the intermediate good is determined by the total net R&D of all firms in the sector, as follows:

$$Q_t = Q_{t-1}(1 + (n_t^\alpha + m\widehat{n}_t^\alpha)^{\frac{1}{\alpha}}) \tag{3}$$

Equation 3 describes the evolution of quality, as a function of: last period's quality, Q_{t-1}; the R&D effort of the intermediate good firm, n_t; the R&D of each of its rivals, $\widehat{n}_t$; the number of rivals it faces, m, and the degree of R&D duplication, α. A higher α indicates higher duplication. The quality evolution equation implies that higher R&D jointly generated by all firms can act as a positive externality if there is not too much R&D duplication present because it enhances the quality of the intermediate good each period. The value function of an intermediate good firm, a function of last period's quality, is as follows:

$$V_t(Q_{t-1}) = \max_{n_t, l_t}\{\frac{n_t}{n_t + m\widehat{n}_t}[(1-a)A_t h_t^a l_t^{\beta(1-a)} Q_{t-1}^{1-a}(1+(n_t^{\alpha}+m\widehat{n}_t^{\alpha})^{\frac{1}{\alpha}})^{1-a} - w_t l_t] - w_t n_t + \frac{1}{1+r_{t+1}} V_{t+1}(Q_t)\} \quad (4)$$

where $X_t = l_t^{\beta}$. Note l_t is labor input to the intermediate good sector, β is the productivity parameter for labor input to the intermediate good sector, w_t is the wage rate, and r_{t+1} is the exogenous interest rate.

Intermediate good firms choose R&D labor and the amount of labor input to the intermediate good sector. R&D investment increases the degree of quality, which increases expected total revenues for the firm in the current period. In turn, higher quality enhances the expected future value of the firm. The cost of increasing R&D to the firm is the real wage rate. Importantly, in Equation 4, the endogenous probability of the success of an intermediate good firm, $\frac{n_t}{n_t + m\widehat{n}_t}$, is determined by its R&D effort relative to its rivals' R&D effort. The higher an intermediate good firm's R&D effort is relative to its rivals, the higher are its chances of dominating the market.

II. Theoretical & Numerical Example Results

The comparative statics generated from the theoretical model and the results from the numerical example allow me to shed some light on the eight questions posed at the outset of this paper, as follows:[2] (1) Competition has an ambiguous effect on firm R&D effort because: (a) whether competition encourages firm R&D effort, depends on the current level of competition, and, (b) whether competition encourages firm R&D effort depends on the degree of R&D duplication, with higher degrees of duplication being associated with an increasingly negative impact of competition on intermediate good firm R&D effort. Part (b) is an expected result because it implies that when the impact of R&D on intermediate good quality is weak, firms will naturally decrease R&D effort; (2) Yes, although increased competition may dampen innovation at the individual firm level, the simple increase in the number of firms in the industry due to increased competition, and thus, the increase in total effective useful R&D in the sector, may, nonetheless, dominate the effect at the firm level, resulting in an overall increase in growth. I label this key result the Volume Effect. Therefore, *given a large enough number of firms, (and hence strong enough competition), sectoral innovation and growth may, nonetheless, thrive, even in face of some duplicative R&D;* (3) Higher R&D duplication is associated not only with decreases in firm R&D effort, but also with decreases in the growth rate and lifetime utility, as to be expected; (4) An inverted U relationship between competition and growth can be generated in the case of moderate duplication, a result consistent with Aghion and Howitt et al. (2002). In other words, in some cases, some competition is good for growth but too much may be detrimental to growth; (5) Between one and three rivals appears to maximize the growth rate, assuming moderate duplication; (6) Competition may enhance equilibrium lifetime utility or be detrimental to it; again, it depends critically on the degree of R&D duplication; (7) Yes, the growth rate and lifetime utility may respond differently to competition. For example, when there is at least moderate R&D duplication present, utility appears to be maximized in a monopolistic situation and this differs from the behavior of the growth rate, which is maximized when there are between one and three rivals. This is due to the fact that lifetime utility is a function of both current consumption and the growth rate, implying lifetime utility may be decreasing while growth is increasing because current consumption, (the other component of utility), is decreasing; and, (8) With moderate duplication, increasing competition appears to consistently decrease utility; with moderate duplication, a monopolistic situation is associated with the highest lifetime utility. However, and interestingly, if there is no R&D duplication, my results suggest that it is possible to generate an unexpected inverted U relationship between competition and lifetime utility, which is maximized at one rival. As anticipated, a positive R&D externality suggests that more competition is always better for utility. In short, barring the case of a positive R&D externality, my model suggests that it is possible to derive the specific optimal level of utility-maximizing competition to be either one or two firms in the sector.

One may ask why lifetime utility is not always maximized by a monopolistic outcome since it is often assumed that monopolies are the most efficient forms of market structure, given their economies of scale. The answer lies in the fact that this model relies on product innovations and quality enhancements. A monopoly will not undertake product innovations unless there is sufficient luxury good demand and the opportunity cost of not improving a product for a monopolist is the possibility of lower expected revenues from the luxury good demanding part of the market. In contrast, firms under competitive threat must improve quality irrespective of the degree of luxury good demand. With the assumption of drastic innovations and only one winner each period, the opportunity cost of not improving a product in a competitive environment, is going out of business.

III. Conclusions

Intriguingly, my results suggest that not only can my model generate an inverted U between competition and growth, but it can also generate an inverted U between competition and utility, implying it may be possible to determine the specific growth or utility-maximizing level of competition. An important message from this paper for policy makers who wish to maximize growth rates emanates from the Volume Effect, which is simply: look at the forest (namely, the sector/economy), not necessarily only the trees (namely, the firms), as they may move in different directions when competition increases, depending on the degree of R&D duplication. A second message is that because of the key role played by R&D duplication in determining whether competition is a positive, negative or ambiguous force, it becomes important to accurately define R&D duplication - a difficult task, at best. Only when this is agreed upon, will it be possible to turn to the question: How much competition is too much? One could argue that more than one firm chasing the same prize is wasteful and represents a market failure. In other words, duplication of R&D effort costs society in labor effort and this labor effort could have been employed elsewhere to produce another good; this is the typical rent-seeking argument. As to be expected, my results suggest that higher R&D duplication generally implies competition is worse for firm R&D effort, the growth rate, and lifetime utility. However, real life examples of similar R&D effort by different firms, such as R&D which resulted in different classes of HIV/AIDS drugs becoming available, suggest there may be room for more than one version, as hindsight has demonstrated. Moreover, R&D effort intended to treat AIDS has resulted in treatments for entirely different diseases (the cousin of 3TC, a drug designed to combat AIDS, is now the main treatment for Hepatitis B). R&D effort initially for the treatment of cancer, resulted in becoming the first widely-utilized AIDS drug, AZT. The point is that it is doubtful, if one takes a long enough perspective, that, in most sectors, perfect, or even moderate, R&D duplication exists. Rachel Griffith et al. (2000), suggest that, in most sectors, the degree of sectoral duplication of R&D is not extremely high. More specifically, Adam Jaffe (1986), implies that there is actually little or no duplication of R&D effort in most sectors. Incorporating this evidence into my model would imply that more competition is always beneficial to both growth and lifetime utility. In sum, this model highlights the importance of separating the impact of competition on the firm, from the impact on the economy, which may be different. It also emphasizes the significance of carefully defining and understanding what we mean by R&D duplication.

References

[1] **Aghion, Philippe, Nicholas Bloom, Richard Blundell, Rachel Griffith, and Peter Howitt.** 2002. "Competition and Innovation: An Inverted U Relationship." http://post.economics.harvard.edu/faculty/aghion/papers.

[2] **Aghion, Philippe, and Peter Howitt.** 1992. "A Model of Growth Through Creative Destruction." *Econometrica*, 60(2): 323-351.

[3] **Barro, Robert J., and Xavier Sala-i-Martin.** 2004. *Economic Growth*. Cambridge: The MIT Press.

[4] **Dubey, Pradeep, and Chien-wei Wu.** 2001. "Competition Prizes: When Less Scrutiny Induces More Effort." *Journal of Mathematical Economics*, 36(4): 311-336.

[5] **Griffith, Rachel, Stephen J. Redding, and John Van Reenen.** 2000. "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries." Centre for Economic Policy Research Discussion Paper 2457.

[6] **Jaffe, Adam B.** 1986. "Technological Opportunity and Spillovers of R&D." *American Economic Review*, 76(5): 984-1001.

FOOTNOTES

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1. Aghion and Howitt et al. (2002), suggest that an important extension to their model would be to introduce entry and entry threat as a method of measuring competition. My model does exactly that, and, importantly, it also shares a similar conclusion with their model, despite the fact that our models are different.

2. In the theoretical model, I assume the following: firms use a Nash Equilibrium concept in forming expectations of other firms' behavior, meaning they take the actions of the other firms as given; a competitive equilibrium exists; and, the economy is operating on the balanced growth path. In the numerical example, I examine various degrees of duplication from heavy duplication to a positive R&D externality. Specifically, the degrees of duplication examined are $\alpha = 2.0$, $\alpha = 1.5$, $\alpha = 1.0$, and $\alpha = 0.50$. I assume $r^* = 0.04$, following the standard macroeconomic literature. I also assume that either a moderate or relatively high rate of return to knowledge accumulation exists, where $a = 0.30$ or $a = 0.50$. Finally, I assume $\beta = 0.70$. Other parameter values were analyzed and the additional results generated are available from the author upon request.