MAINTENANCE AND DESTRUCTION OF R&D LEADERSHIP*

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In the standard Schumpeterian-growth models only follower firms invest in R&D activities and larger economies grow faster. Since these results are counterfactual, this paper reveals that leader firms often support R&D activities and economic growth can be independent of the market size. In particular, the maintenance of R&D leadership increases with: (i) the technological-knowledge gap between leader and followers, since a firm-specific learning effect of accumulated technological knowledge from past R&D is considered, (ii) the leaders' strategies that delay the next successful R&D supported by some follower firm, (iii) the market size, and (iv) the up-grade of each innovation.

1 INTRODUCTION

Most Schumpeterian-growth models (e.g. Grossman and Helpman, 1991) assumed that the leadership of the firms that produce state-of-the-art qualities is only temporary, as they are permanently subject to destruction by new qualities. That is, since all firms, the leader and followers, have access to the same R&D technology in each good, once a firm achieves success and becomes a monopoly, it does not support new R&D activity. In fact, in this context, the incentives of leaders to invest in R&D are lower due to the 'Arrow (1962) effect', i.e. the expected gain of the leader is just the difference between expected profits with the next successful R&D and the existing one, while the expected gain for each follower is given by all the expected profits with the next successful R&D.

However, the empirical evidence shows that this pattern of leapfrogging is unrealistic (e.g. Scherer, 1984, ch. 11; Blundell *et al*., 1999; Etro, 2004; Aghion and Griffith, 2005). In an issue of *The Economist* (2004), the authors of the 'Economics Focus' column stated that leaders may have a far more vital role in producing innovations than previously thought; they further expressed doubts about the prevailing economic theory according to which

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the 'monopolist (leader) should have far less incentives to invest in creating innovations than a firm in a competitive environment (follower)'.[1]

A number of solutions to this contradiction have been projected; most of these are rooted in some technological-knowledge advantage of the leader, which, in turn, implies that its incentives to support R&D can offset the 'Arrow effect'.

Thus, some studies assume that leaders have R&D cost advantage over followers and/or there are diminishing returns in R&D effort at the firm level, implying that they can apply resources to R&D (e.g. Segerstrom and Zolnierek, 1999; Segerstrom, 2007). Others assume that customers' loyalty assures the leader cheaper distribution channels (e.g. Canton and Uhlig, 1999). Others further present models in which leaders apply resources in rent-protecting activities to extend the monopoly duration (e.g. Dinopoulos and Syropoulos, 2004, 2007). In Denicolò (2001) persistent leadership is explained by assuming non-drastic innovations and a move advantage in the next patent race. In Chang and Wu (2006), in turn, the technological knowledge is accumulated by R&D expenditures and by production experiences, which increases persistent leadership. Additional studies such as Aghion *et al.* (2001) and Klette and Kortum (2004) analyse the R&D incentives of leaders; in the former, followers support R&D to catch up with leaders and then they can support R&D to enhance their own goods; in the latter, leaders support R&D to enhance other leaders' goods and become multi-good firms.

Another odd feature of most Schumpeterian-growth models is that the economy's growth rate increases as its size/scale does. The literature has been debating the role of scale effects since Jones (1995a) criticized the seminal work of Romer (1990), on the grounds that it unreasonably predicted positive market-size effect on growth. In addition to theoretical arguments, several authors have supplied the debate with empirical evidence against strong scale effects (e.g. Backus *et al.*, 1992; Jones, 1995b; Dinopoulos and Thompson, 1999; Zachariadis, 2003). Starting with Jones (1995a) himself, who has properly modified Romer's (1990) R&D technology, several modelling efforts have been made to eliminate scale effects.[2]

We develop an endogenous growth model to explain why all firms, leaders and followers, can support R&D activities and in which economic growth can be scale independent. We consider a standard economic structure: the production of perfectly competitive final goods uses labour together with quality-adjusted intermediate goods, which, in turn, use innovative designs under monopolistic competition.

Our model differs from standard Schumpeterian-growth models by jointly considering three crucial assumptions reflected in the R&D sector: (i)

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[1]See Sutton (2007) for theoretical and empirical issues about the evaluation of leaders' maintenance.

[2]See Jones (1999) and Segerstrom (1998) for detailed discussion of scale effects and ways to avoid them.

there can be either constant or diminishing returns to R&D effort at the firm level (in line with, for example, Kortum, 1993), (ii) the leader has no cost advantage over followers, but (ii.1) it has a specific endogenous positive learning effect of accumulated technological knowledge from past successful R&D (along the lines of, for example, Gruber, 1994) and (ii.2) it can use its position to preserve economic revenue by delaying the successful R&D supported by followers (as stated by, for example, Dinopoulos and Syropoulos, 2004, 2007).

In particular, the latter assumption allows us to remove the scale effects. In our case, scale effects are connected to the size of profits that, in each period, accrue to the leaders; a larger market expands profits and, thus, the incentives to allocate resources to R&D, thereby increasing the economic growth rate. They can be removed by assuming that the difficulty in conducting R&D is proportional to the size of the market measured by the labour level. This is consistent with the literature which observes that increases in costs of scale are related to strategies, like technical barriers, undertaken by leaders to delay successful R&D by followers, with the objective of prolonging their temporary monopoly power (e.g. Dinopoulos and Syropoulos, 2004, 2007). The considered scale-removing 'permanent-effects-on-growth' specification, in the Dinopoulos and Segerstrom (1999) terminology, is compatible with endogenous economic growth.

Since the two mentioned strands of the literature—R&D leadership and scale effects—have been dealt with separately, the implications of merging them have not yet been explored. In particular, we show that persistent leadership increases with the: (i) technological-knowledge gap between leader and followers, (ii) market size, (iii) up-grade of each innovation, and (iv) strength of the leaders' strategies that delay the next innovation, which also contribute to rule out scale effects. Indeed, in these situations, R&D supported by leaders is relatively more profitable.

The paper is organized as follows. In Section 2, we present the model. In Section 3, we derive the steady state and we describe the results. In Section 4, we conclude.

2 THE MODEL

The economy is populated by a time-invariant number of individuals, which supply labour, consume final goods and own firms. Final goods are produced under perfect competition by combining labour and quality-adjusted intermediate goods. Quality-adjusted intermediate goods are produced under monopolistic competition by using aggregate output and innovative designs. Designs are obtained through R&D activities.

Since we are interested in the competition between producers of each intermediate good, the Schumpeterian approach, in which R&D is directed at developing new vertically differentiated qualities, is more suitable than the

horizontal one, where R&D is directed at developing new differentiated goods. Our option is thus in line with, for example, Scherer (1980), who quotes survey evidence indicating that the lion's share of R&D by firms is directed at enhancing existing goods, and also with Scherer (1984), who shows that both leaders and followers can support R&D activities.

2.1 Consumers

A time-invariant number of individuals decide between consumption and savings. The individual infinite horizon lifetime utility is the integral of a discounted constant inter-temporal elasticity of substitution (CIES) utility,

$$U(t) \equiv \int_0^\infty \left[\frac{c(t)^{1-\theta} - 1}{1-\theta} \right] \exp(-\rho t) \, dt \tag{1}$$

where $c(t)$ is individual consumption at time t, $\rho > 0$ is the homogeneous discount rate, and $\theta > 0$ is the inverse of the inter-temporal elasticity of substitution.

The individual budget constraint equalizes income earned to consumptions plus savings, at each t. Savings consist of accumulation of financial assets—K, with return r—in the form of ownership of the firms that produce intermediate goods in monopolistic competition. The value of these firms, in turn, corresponds to the value of patents in use. The budget constraint, expressed as Savings + Consumptions = Income, is

$$\dot{K}(t) + c(t) = r(t)K(t) + w(t) \tag{2}$$

where $\dot{K}(t)$ is the change in $K(t)$ at time t, and $w(t)$ is the wage of the individual at t.

Maximizing (1) subject to (2) yields the solution for the consumption growth rate, $\hat{c}(t)$, which is independent of the individual and is the standard Euler equation:

$$\hat{c}(t) = \hat{C}(t) = \frac{r(t) - \rho}{\theta} \qquad \text{where} \quad C(t) \equiv c(t)L \tag{3}$$

2.2 Final and Intermediate Goods

Production of each final good $n \in [0, 1]$ under perfect competition uses labour, L, and a set of quality-adjusted intermediate goods $j \in [0, J]$. The constant returns to scale production function of final good n, Y_n, at time t is

$$Y_n(t) = A \left[\int_0^J (q^{k(j,t)} x_n(k, j, t))^{1-\alpha} \, dj \right] L_n^\alpha \tag{4}$$

where $A > 0$ is the exogenous level of productivity and $0 < \alpha < 1$ is the labour share in production. The integral denotes the aid of intermediate goods to

production. In the Schumpeterian tradition, the quantity, x_n, is quality-adjusted, i.e. $q > 1$ is the size of each quality upgrade and k is the top quality rung at t.[3] Due to zero profit equilibrium by producers of $n \in [0, 1]$, the demand for the top quality of j by the producer of n is

$$x_n(k, j, t) = L_n(t) \left[\frac{p_n(t)A(1-\alpha)}{p(k, j, t)} \right]^{1/\alpha} q^{k(j,t)[(1-\alpha)/\alpha]} \tag{5}$$

where p_n and $p(j)$ are, respectively, the prices of n and j. A higher: p_n increases the marginal revenue product of the factors, encouraging firms to rent more intermediate goods; L_n implies more labour to use intermediate goods, raising demand; $p(j)$ implies lower demand, since the demand curve for intermediate goods is downward sloping.

Plugging the demand for top quality in each j (5) into (4),[4] the supply of n is

$$Y_n(t) = A^{1/\alpha} \left[\frac{p_n(t)(1-\alpha)}{p(j, t)} \right]^{(1-\alpha)/\alpha} L_n Q(t) \qquad \text{where} \quad Q(t) \equiv \int_0^J q^{k(j,t)\alpha^{-1}(1-\alpha)} \mathrm{d}j \tag{6}$$

measures the aggregate technological knowledge.

We define the aggregate output, $Y(t) \equiv \int_0^1 p_n(t)Y_n(t)\mathrm{d}n = \exp\left[\int_0^1 \ln Y_n(t)\mathrm{d}n \right]$, as the numeraire, i.e. we normalize its price to one at each t. Resources, Y, can be used in production of intermediate goods, X, in R&D activities, D, and in consumption, C.

Since Y is the input of j, the marginal cost of producing j is one. Its production also involves a start-up R&D cost, which can be recovered because a patent law assures positive profits at each date for a certain amount of time. The profit-maximization price yields the stable (over t, across j and for all k) mark-up $p(k, j, t) = p = 1/(1 - \alpha) > 1$.

Since the leader is the one legally allowed to produce the top quality,[5] it will use pricing to wipe out lower qualities. Depending on whether $q(1 - \alpha) > 1$ or $q(1 - \alpha) < 1$, the leader will use either the monopoly pricing $p = 1/(1 - \alpha)$ or the limit pricing $p = q$ to capture the entire market. We assume that limit pricing strategy is binding (as, for example, Grossman and Helpman, 1991, ch. 4; Afonso, 2008) and thus is used by all firms.

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[3]Since the various qualities of j are perfect substitutes, due to profit maximizing by monopolist firms of $j \in [0, J]$, in equilibrium only the top quality of each j is demanded by final-goods firms.

[4]As we will see below, the profit maximizing by monopolist firms implies that $p(j)$ is independent of j.

[5]That is, the inventor has the monopolistic profit under the protection of the patent until the next top quality.

As q is the quality advantage over the closest follower, the leader can successfully capture the entire market by selling at a price slightly below q;[6] thus, q is also an indicator of the market power of the incumbent firm in each intermediate good.

2.3 R&D Sector

The results of R&D are designs, which improve the quality of intermediate goods, while creatively destroying the profits from previous qualities (e.g. Grossman and Helpman, 1991, ch. 4; Afonso, 2008). In contrast with initial Schumpeterian-growth models (e.g. Grossman and Helpman, 1991, ch. 4) in which only followers researched a higher-quality good to deprive the current leader, in our case the current leader enters the R&D process (as well as followers) in order to maintain its leadership.

Let $I_z(k, j, t)$ denote the instantaneous probability of successful R&D in the next top quality, $k(j, t) + 1$, by the leader, $z = 1$, or by a follower, $z = f$, in j at t,

$$I_z(k, j, t) = \underbrace{d_z(k, j, t)^\delta}_{(i)} \underbrace{(F^{\delta-1})^{\eta_z}}_{(ii)} \cdot \underbrace{\beta q^{k_z(j,t)}}_{(iii)} \cdot \underbrace{\zeta^{-1} q^{-\alpha^{-1}k(j,t)}}_{(iv)} \cdot \underbrace{L^{-\xi_z}}_{(v)} \tag{7}$$

where:

(i) $d_z(k, j, t)$ is the flow of Y devoted to R&D by z in j at t, and $0 < \delta \leq 1$ measures the degree of returns to R&D effort at the firm level;[7]

(ii) F is the number of followers (under free entry, $F \to +\infty$), and $\eta_f = 1$ and $\eta_l = 0$;

(iii) $\beta q^{k_z(j,t)}$, $\beta > 0$, is the positive learning effect of accumulated public technological knowledge from past R&D in j at t (e.g. Connolly, 2003), which, since $k = k_1 > k_f$, implies that the leader has an R&D advantage over followers; defining $\tilde{q}$ as the relative technological-knowledge level of f, and Q_l (= Q in (5)) and $Q_f \equiv \int_0^J q^{k_f(j)\alpha^{-1}(1-\alpha)}dj$ as the technological knowledge of leaders and followers, respectively, we have

$$q^{k_f(j,t)} = q^{k(j,t)} \frac{q^{k_f(j,t)}}{q^{k(j,t)}} = q^{k(j,t)}\tilde{q}(j,t) = q^{k(j,t)} \frac{\dfrac{Q_f(t)}{J}}{\dfrac{Q_l(t)}{J}} = q^{k(j,t)}\tilde{Q}(t) \qquad 0 < \tilde{Q}(t) < 1;[8] \tag{8}$$

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[6]Since the lowest price that the closest follower can charge without negative profits is one.

[7]Empirical evidence on returns to scale to R&D level is inconclusive (e.g. Kortum, 1993; Lach, 1995); and diminishing returns may arise because firms have a limited number of expected useful ideas at each t.

[8]That is, to have an adequate measure of $\tilde{q}(j,t)$, we assume that the technological-knowledge gap between followers and the leader in j is described by an average (representative) intermediate good, $\tilde{Q}$.

(iv) $\zeta^{-1}q^{-\alpha^{-1}k(j,t)}$, $\zeta > 0$, is the adverse effect caused by the increasing complexity of quality improvements in j at t (e.g. Kortum, 1997);

(v) $L^{-\xi_z}$ ($L > 1, 1 \geq \xi_f > \xi_l > 0$) captures the idea that the difficulty of introducing new qualities is proportional to the market size, due to coordination among agents, processing of ideas, informational, organizational, transportation and marketing costs (e.g. Dinopoulos and Segerstrom, 1999; Dinopoulos and Thompson, 1999). Moreover, by assuming that $1 \geq \xi_f > \xi_l > 0$, we reflect in R&D the leaders' strategies (e.g. Dinopoulos and Syropoulos, 2004, 2007), which, by decreasing ξ_l and thus favouring $I_l(k, j, t)$, delay the next successful R&D by followers.[9]

We must stress that: (i) since β/ζ is independent of z, our option is different from, for example, Segerstrom and Zolnierek (1999) in which the leader has an R&D cost advantage over followers, (ii) since, in each j, the leader and followers support R&D and make their R&D decisions simultaneously, independently and are free to adjust R&D inputs at t, the probability of success is $I(k, j, t) = I_l(k, j, t) + \sum_{f=1}^{F(=+\infty)} I_f(k, j, t)$, and (iii) since followers in j enjoy the same technology and their returns are independent (7) allows for aggregation.

3 Steady State

We start the steady-state analysis by comparing the profits of followers taking over the leader place, $\Delta\Pi_f(k, j, t) = \Pi_f(k, j, t)$, with the incremental profits of leaders replacing themselves, $\Delta\Pi_l(k, j, t)$. Since limit price is binding and the profits for the producer of j using a research of quality k at t relies on the mark-up and on the demand, we have[10]

$$\Delta\Pi_f(k, j, t) = L(q-1)\left[\frac{A(1-\alpha)}{q}\right]^{\alpha^{-1}} q^{k(j,t)(1-\alpha)\alpha^{-1}} \tag{9a}$$

$$\Delta\Pi_l(k, j, t) = L(q-1)\left[\frac{A(1-\alpha)}{q}\right]^{\alpha^{-1}} q^{k(j,t)(1-\alpha)\alpha^{-1}}\left[(q+1)q^{-\alpha^{-1}} - q^{(\alpha-1)\alpha^{-1}}\right] \tag{9b}$$

From equations (9a) and (9b), the gain to a follower is greater so long as $q^{1/\alpha} > 1$, which is guaranteed by assumptions $q > 1$ and $0 < \alpha < 1$, i.e. the

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[9]Thus, we distinguish successful R&D leading to creative destruction from leaders' strategies that slow down the process of creative destruction. That is, we consider that leaders acquire specific technological knowledge that, once used, can partially and temporarily insulate them from the threat of leapfrogging by followers. Such strategies include, for example, trade secrecy and time pacing (e.g. Eisenhardt and Brown, 1998).

[10]As the leader firm will now be selling a product twice as productive as its nearest competitor, it will be able to use a price slightly below q^2, but it will also lose its profits from its previous successful research.

incremental gain of a two-step quality advantage to a leader is smaller than the gain of a one-step quality advantage to a follower, since the follower goes from having no profits to having profits when it takes over the leader position. This is the 'replacement or Arrow (1962) effect'.

Let $V_z(k, j, t)$ denote the expected discounted profit earned by z, which sells a quality k of j at t;[11] the problem is tractable because $V_z(k, j, t)$ only relies on the quality k and not separately on t or j. The Hamilton–Jacobi–Bellman equation for l in j is

$$r(t)V_1(k, j, t) = \max_{d_1(k,j,t) \geq 0} \{\Pi_1(k, j, t) - d_1(k, j, t) + I_1(k, j, t)[V_1(k+1, j, t)$$
$$-V_1(k, j, t)] + I_F(k, j, t)[V_F(k+1, j, t) - V_1(k, j, t)]\} \tag{10}$$

That is, l enjoys the monopoly profit flow $\Pi_1(k, j, t)$ while supporting the $d_1(k, j, t)$ cost, with the purpose of maintaining its position. With probability $I_1(k, j, t)$, l is successful and its value shoots up: $V_1(k + 1, j, t) - V_1(k, j, t)$. With probability $I_F(k, j, t)$, l is replaced by some f and its value drops: $V_F(k + 1, j, t) - V_1(k, j, t)$. Similarly, for each f in j

$$r(t)V_F(k, j, t) = \max_{d_f(k,j,t) \geq 0} \{I_f(k, j, t)[V_1(k+1, j, t) - V_F(k, j, t)] - d_f(k, j, t)$$
$$+ [I_{F-1}(k, j, t) + I_1(k, j, t)][V_F(k+1, j, t) - V_F(k, j, t)]\} \tag{11}$$

where $I_{F-1}(k, j, t)$ is the probability of success by all the other followers together. Each f earns no profit flow and supports the $d_f(k, j, t)$ cost to achieve the success $I_f(k, j, t)$. In this case, it becomes a leader and its value rises: $V_1(k+1, j, t) - V_F(k, j, t)$. With probability $I_{F-1}(k, j, t) + I_1(k, j, t)$, some other firm, either another f or l, obtains the next patented design and, thereby, f will remain so in the next R&D process.

The equalities (10) and (11) mean that the maximized expected return on the l and f value, respectively, due to a change in k must equal the return on an equally sized investment in a risk-less bond, $r V_z$; (10) and (11) also show that leaders gain less since $V_1(k + 1, j, t) - V_1(k, j, t) < V_1(k + 1, j, t) - V_F(k, j, t)$ (note that under free entry $V_F(k, j, t) = 0$).[12]

From (7) and (8), the first-order conditions for profit maximization from (10) and (11) (i.e. $[\partial r(t) V_z(k, j, t)]/[\partial d_z(k, j, t)] = 0$) and free entry, the relative innovation rate of leaders is

$$\bar{I} \equiv \frac{I_1}{I_F} = \left\{\tilde{Q}^{-1} L^{\xi_f - \xi_1}\left[1 - q^{(\alpha\delta)^{-1}(\alpha-1)}\right]^\delta\right\}^{(1-\delta)^{-1}} \tag{12}$$

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[11]Hence, V is the market value of the patent or the value of the monopolist firm owned by individuals.

[12]Since under free entry F → +∞, then the individual contribution of any follower firm to the aggregate innovation rate of all followers is negligible, i.e. the market value of each follower equals zero at each t.

where I_l and I_F are the equilibrium probabilities of successful R&D by the leader and by followers, respectively. I_l and I_F turn out to be independent of j and k, since the positive effect of the quality rung on profits (see (9a) and (9b)) and on the learning effect (see (7)-(iii)) is totally offset by its effect on the complexity cost (see (7)-(iv)). Scale effects could arise through the market size, as discussed since Jones (1995a, 1995b).

Equation (12) has very intuitive implications, summarized in Theorems 1 and 2.

Theorem 1: Under constant returns to R&D, i.e. computing $\lim_{\delta \to 1} \overline{I}$, apart from the particular case in which $1 - q^{\alpha^{-1}(\alpha-1)} = \tilde{Q}L^{-\xi_f + \xi_l}$, R&D activities are only supported by

(i) leaders when $1 - q^{\alpha^{-1}(\alpha-1)} > \tilde{Q}L^{-\xi_f + \xi_l}$;
(ii) followers when $1 - q^{\alpha^{-1}(\alpha-1)} < \tilde{Q}L^{-\xi_f + \xi_l}$.

Thus, when the technological-knowledge gap between the leader and followers, $\tilde{Q}^{-1}$, is large, and/or the leaders' strategies that delay the next innovation are intense (small ξ_l), and/or the market size, L, is large, and/or each quality upgrade, q,[13] is higher, only the leader supports R&D. In this case, $1 - q^{\alpha^{-1}(\alpha-1)} > \tilde{Q}L^{-\xi_f + \xi_l}$, its R&D advantage more than offsets its disadvantage in terms of benefits from successful R&D, i.e. the 'Arrow (1962) effect'. Otherwise, $1 - q^{\alpha^{-1}(\alpha-1)} < \tilde{Q}L^{-\xi_f + \xi_l}$, only followers support R&D activities since the leader cannot offset the difference in benefits from successful R&D.

Hence, even under constant returns to R&D, as usual in Schumpeterian-growth models, Theorem 1 implies when $1 - q^{\alpha^{-1}(\alpha-1)} > \tilde{Q}L^{-\xi_f + \xi_l}$ occurs, only leaders support R&D activities. However, to better accommodate empirical evidence (according to which both leaders and followers participate in R&D—e.g. Blundell *et al.*, 1999), we need to consider diminishing returns to R&D. From (12), we have

Theorem 2: Under diminishing returns to R&D, i.e. with $0 < \delta < 1$,

(i) R&D activities are supported by both leaders and followers;
(ii) leaders (followers) support relatively more R&D when $\tilde{Q}$ is low (high), and/or ξ_l is low (high), and/or L is high (low) and/or q is high (low).

Therefore, under diminishing returns to R&D, our theoretical results are more attractive since leaders always support R&D activities. Bearing in mind, for example, Scherer (1984, ch. 11), firms with fewer than 1000 employees (a proxy for followers) were responsible for 47.3 per cent of innovations, which indicates that the R&D advantage is apparently divided between leaders and followers.

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[13]When q is very high (i.e. an innovation is drastic), the leader can engage in monopoly pricing.

It is pertinent to stress the weight of the leaders' positive learning effect from past R&D (7)-(iii), and the leaders' strategies related with scale effects to delay successful R&D by followers (7)-(v), in theoretical results summarized in Theorems 1 and 2.

The equilibrium R&D can be translated into the growth rate of Q, i.e. into the path of technological knowledge, which is given by $\hat{Q} = (I_1 + I_F)\left[q^{\alpha^{-1}(1-\alpha)} - 1\right]$ because the same R&D intensity applies to all intermediate goods—as stated above, for each j (7)-(iii) together with (7)-(iv) exactly offsets the positive effect of the quality rung on profits. For example, under constant returns to R&D, $\delta = 1$, and with $1 - q^{\alpha^{-1}(\alpha-1)} < \tilde{Q}L^{-\xi_f + \xi_l}$, the following expression (where the equilibrium I_F given r is plugged in) is obtained:

$$\hat{Q} = \left\{\underbrace{\frac{\beta}{\zeta} L^{1-\xi_f} \frac{q-1}{q} [A(1-\alpha)]^{\alpha^{-1}} \tilde{Q} - r}_{\equiv I_F}\right\} [q^{(1-\alpha)/\alpha} - 1] \tag{13}$$

Since Y, X, D and C are multiples of Q, the stable steady-state endogenous growth rate, g^*, which through (3) also implies a stable steady-state r, r^*, is

$$g^* = \hat{Q}^* = \hat{Y}^* = \hat{X}^* = \hat{D}^* = \hat{C}^* = \hat{c}^* = \frac{r^* - \rho}{\theta} \tag{14}$$

Thus, r^* is obtained by setting $\hat{C}$, in (3), equal to $\hat{Q}$, in (14) in which $\delta = 1$ and $1 - q^{\alpha^{-1}(\alpha-1)} < \tilde{Q}L^{-\xi_f + \xi_l}$, and then g^* results from plugging r^* into (3); thus, r^* is

$$r^* = \left\{[q^{(1-\alpha)/\alpha} - 1]\theta + 1\right\}^{-1}$$
$$\left\{\frac{\beta}{\zeta} L^{1-\xi_f} \frac{q-1}{q} [A(1-\alpha)]^{\alpha^{-1}} \tilde{Q}[q^{(1-\alpha)/\alpha} - 1]\theta + \rho\right\} [q^{(1-\alpha)/\alpha} - 1] \tag{15}$$

Given (15), it immediately follows that:

Theorem 3. If scale effects are removed, the steady-state growth rate is scale invariant.

Indeed, from (15), when $\xi_f = 1$, the adverse effect of market size (see (7)-(v)) offsets the scale effect on profits (see (9a) and (9b)) and, in line with empirical evidence (e.g. Jones, 1995b), the steady-state growth rate is scale independent.

4 Concluding Remarks

A common result of most Schumpeterian R&D growth models is that leaders do not support R&D and larger economies always grow faster. However,

empirical evidence points out that both followers and leaders play important roles in producing innovations and that economic growth is independent of relevant scale effects.

By building an endogenous growth model in which R&D is applied to intermediate goods used in the production of final goods, we propose, in line with the observed behaviour of firms, possible new reasons why leaders can often support R&D. We find that when the technological-knowledge gap between the leader and followers is large (small), and/or the leaders' strategies that delay the next innovation are strong (weak), and/or the market size is large (small) and/or each quality upgrade is high (low), R&D is only supported by the leader (followers) under constant returns to R&D effort or is relatively more supported by the leader (followers) under diminishing returns.

Moreover, by assuming that the difficulty in conducting R&D is proportional to the size of the market measured by the stock of labour, our model is consistent with the time-series evidence against important scale effects on economic growth.

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