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Market Structure and Innovation Revisited: Endogenous Productivity, Training and Market Shares*

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December 1999

The empirical literature documents positive, negative, and even “inverted-U” relationships between monopoly power, innovation, and growth. Such findings are intuitive since insufficient market power prevents firms from reaping the benefits of up-front R&D investment, while excessive market power reduces the need for further R&D investment. Recent growth models imply, however, that greater market power should unambiguously increase innovation and growth.

We introduce heterogeneous technologies, production costs and market shares into the conventional product variety model to allow for positive effects of competition on technological change and growth. Increased competition is then shown to benefits firms at the technological frontier, while laggard firms experience accelerated product obsolescence. Since skills and technologies are both endogenous, we can also address the "research intensity puzzle." We provide a mechanism by which increases in the share of skilled workers in R&D do not automatically increase the growth rate - a key counterfactual finding in R&D based growth models. In contrast we suggest that the response to the growth rate to a higher share of labor in R&D depends on the level of development.

JEL classification: *031, 041*

Key Words: *Market Structure and Innovation, Endogenous Market Shares, Product Cycles*

*****We thank Charles Engel, Fahad Khalil, Thomas Osang and Steve Turnovsky and seminar participants at Nuffield College, and the Universities of Copenhagen, Rotterdam, Tilburg, Dortmund, Tübingen and München for helpful suggestions.
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1) Introduction

Recent efforts to integrate endogenous technological change into models of economic growth have led to two distinct approaches. Quality Ladder models examine the effects of perpetual quality increases for a fixed number of goods, while Product Variety models feature an ever expanding set of products with identical costs and market shares. Quality ladder models can thus account for continued innovation and creative destruction, while product variety models explain increasing product proliferation in the market place. However, only heuristic interpretations of *both models together* can attempt to capture observed industry dynamics that consist of an endogenous number of varieties with distinct technologies and market shares. This provides the first motivation for this paper: to integrate heterogeneous technologies into a product variety model and allow for expanding variety, increasing technology and distinct market shares across firms.

Implicit in the above two approaches to technology and growth is a second shortcoming that relates to the relationship between market power, rates of innovation and growth. The voluminous empirical literature documents both positive and negative relationships between monopoly power and innovation.[1] Scherer (1967) and Levin, Cohen and Mowery (1985) even find an "inverted-U" relation. Such findings are intuitive since insufficient market power prevents firms from reaping the benefits of up-front R&D investment, while excessive market power reduces the need for further R&D investment.

In clear contrast, the canonical product variety model implies unequivocally that industries with greater degrees of monopoly power should generate more innovations and higher growth rates.[2] In this paper we introduce heterogeneous technologies, production costs and market shares into the conventional product variety model to allow for positive effects of competition on technological change and growth. While maintaining symmetric consumer preferences, we permit innovators to reduce production costs by employing new technologies, charge lower prices and hence capture larger market shares. Since new technologies arrive continuously, each innovator's proximity to the technological frontier

[1] See Cohen and Levin (1989) for a summary. More recently, Nickell (1996), Nickell et al (1997), and Blundell et al (1995) show unambiguously negative correlations.

[2] Quality ladder models do not address the issue because they assume unitary elasticity of substitution, see Aghion and Howitt (1992, 1997).

eventually erodes. The change in the productivity (and hence price) differentials between existing firms and cutting edge firms generate time varying market shares.

Increased competition then has two effects on firms. First, the increased elasticity of demand lowers the markup each firm can charge. Second, the increased ability to substitute one good for another allows consumers to allocate more purchases towards relatively cheaper goods. As a result, recent innovators find that overall profits increase because the shift in the demand toward their product compensates for their reduced markup. Firms using old technologies, in contrast, experience not only declined markups, but also a reduction in demand to magnify the contraction profits as competition increases. As new innovators find their profits and market share increased by competition, more R&D is undertaken and greater positive spillovers from technological change increase the aggregate growth rate.

Previous models find similar results. Aghion, Harris and Vickers (1997) and Kletzer (1997) find that competition and/or imitations may be growth-enhancing in and industry if step-by-step innovation is assumed. Essentially this very plausible approach postulates limited knowledge spillovers, where followers must first catch up to the leader before being able to overtake. The results in our model do not require step-by-step innovation. Adding richer microfoundations, Aghion, Dewatripont and Rey (1997) introduce agency considerations into a model of innovation. This structure may imply a positive effect of competition on innovation, if increased competition raises managerial discipline. Nickel et al (1997) provide empirical support for this approach. Finally, Aghion and Howitt (1996) decompose R&D into creation and adoption of new blueprints to show that endogenous product-line upgrading may lead to higher growth if competition increases. Much like in our model, the driving force is that old lines become obsolete faster and new lines are opened sooner. Neither Aghion and Howitt (1996) nor Aghion et. al. (1997) feature our result that the effect of competition on firm profits is asymmetric, favoring advanced firms and accelerating obsolescence for laggards.

Horizontal and vertical integration have been examined by the industrial organization literature (see, for example, Economides, 1993 and Smulders and van de Klundert, 1995). These models do not replicate a negative relationship between market power and growth. Previous product variety models rely on *identical* productivities of technologies and feature *symmetry* between new and old technologies and goods. Caballero and Jaffe (1993) rely on symmetric technologies but asymmetric consumer preferences to generate asymmetric demand for products. Alternatively, Lai (1998) allows for exogenous reduction in the cost of innovation. In contrast, we specify that productivities of new and old technologies differ and that endogenous production cost advantages allows new variety to capture a larger market share. Instead of relying on asymmetric productivities, Kletzer (1997) models spatial competition and product characteristics, which allows for endogenous and asymmetric research effort across firms.

If we follow Romer (1990) and Grossman and Helpman (1991) and interpret the proliferation of one industry's product line as the performance of a country, the model addresses the "research intensity puzzle" that is at the core of previous R&D based growth models. These models carry the counterfactual implication that the growth rate is either positively, or not at all related to the share of workers allocated to R&D (e.g., Romer 1990 and Jones (1995), respectively). Both implications are counterfactual (see Jones (1995). We show that when market shares, technologies and human capital are modeled to be endogenous, the impact of increased research intensity on growth depends on the *level of development*. Specifically, we find that increased research intensity in high growth countries may be associated with lower growth rates (as in OECD countries), while increased research intensity is shown to be the key to increased growth in developing countries. Essentially we show that the profit destruction effect, due to increased research intensity, may be sufficiently smaller in the low growth countries, which allows the positive effects of higher rates of innovation and increased demand for skilled labor to dominate.

2) Endogenous Productivity and Training in a Product Variety Model

We embed endogenous technology, training and market shares into a product variety model. Previous product variety models that rely on *identical* technologies and *symmetry* between new and old goods (technologies) imply that all goods are priced equivalently and hence consumed in equal proportions. Below we extend a product variety model to allow newer technologies to be more productive, hence cutting edge firms face lower unit costs. Since agents have preferences over varieties, but technologies and unit costs are heterogeneous, asymmetric price reductions generate distinct market shares. This renders the model a hybrid between product variety and quality ladder models.

We follow Eicher (1996) and specify that ever more sophisticated technologies cannot be absorbed into production by agents with stationary knowledge. To this end we endogenize the training decision by firms and specify that firms determine not only how much research should be undertaken, but also how much training workers should receive. The positive side effect of firm-specific training is a positive externality to the general pool of knowledge.

2.1) Tastes

At time t, a representative consumer maximizes utility

$$U(t) = \int_t^{\infty} e^{-r(t-t)} \log\left(\int_{-\infty}^{n(t)} x_i(t)^{\frac{e-1}{e}} di \right)^{e/e-1} dt, e > 1, \tag{1}$$

that extends over the set of products produced, *n(t)*, and they maximize (1) subject to the intertemporal budget constraint:

$$\int_t^{\infty} e^{-(R(t)-R(t))} E(t) dt \leq \int_t^{\infty} e^{-(R(t)-R(t))} h(t) dt + B(t) \tag{2}$$

where r represents the discount rate, where e the elasticity of substitution, $R(t) = \int_0^t r(u) du$ the discount factor, $B(t)$ the individual assets (ownership shares in enterprises), $E(t) = \int_{-\infty}^{n(t)} p_i(t) x_i(t) di$ the expenditures, $p_i(t)$ the price of good i. Through normalizations the wage rate of effective labor is one, hence *h(t)* both, the stock of effective labor in the economy and labor income. Assuming the elasticity of substitution exceeds unity, the introduction of new goods erodes existing varieties' market share. Taking p_i as given, the demand for a good i is

$$x_i(t) = \frac{E(t) p_i(t)^{-e}}{\int_{-\infty}^{n(t)} p_{i'}(t)^{1-e} di'} \tag{3}$$

While equation (3) is standard for product variety models, it highlights that comparatively lower priced goods command a relatively higher market share, and that the introduction of cheaper goods reduces the demand for all existing products. These price and market share dynamics are a key component of this model. Using (3), we can rewrite the utility index in (1) as $E(t)\left(\int_{-\infty}^{n(t)} p_i(t)^{1-e}\, di\right)^{-1/(1-e)}$.

2.2) Production of Final Goods

Firms undertake three activities: creating new technologies, training workers and producing varieties of final goods. Assume there exist $i \in [-\infty, \infty]$ technologies, of which $i \in [-\infty, \ldots N(t)]$ have been discovered at time *t*, the rest are yet to be invented. Technologies are arranged in the order of increasing technological sophistication, so that the latest invention at *t*, *N(t)*, is also the most productive. Before firms can realize the productive potential of their technologies, workers must learn about firm-specific technologies. Let s_i denote the units of training a firm using technology i invests in training. Once training is complete, production can take place. Let *S(t)* be the total number of firms that are engaged in training workers at time *t*. Thus, $n(t) = N(t) - S(t)$ is the most sophisticated good produced at time t.[3]

The production of final good, x_i, requires firm-specific technology, *i*, effective labor, h_{Pi} and firm-specific training, s_i. How productive workers are after experiencing s_i periods of training depends on the workers' constant training efficiency, q

$$x_i = e^i s_i^q h_{Pi}, \qquad (4)$$

where *e* represents the exponential function. *Ceteris paribus,* equation (4) indicates that labor productivity increases when workers are matched with more sophisticated technologies. We assume decreasing returns to training and restrict the training efficiency to $q < 1$. The size of the labor force and the wage rate are normalized to unity, there is no population growth, and hence the production wage at time *t* is simply $h_{Pi}(t)$. The production function implies that firms using newer technologies are more productive and can thus charge a lower price.

Firms utilize the demand for good i, (3), to maximize production profits (excluding training and R&D costs)

$$\underset{p_i}{Max} \quad p_i = p_i x_i - h_{Pi} \qquad (5)$$

which results in the following pricing rule

[3] Below we suppress time subscripts unless required to avoid confusion.

$$p_i = \frac{e}{e-1}\frac{1}{s_i^q e^i} \qquad (6)$$

This pricing rule is crucial, as it incorporates the distinct feature of the model. In contrast to previous product variety models that rely on homogeneous technologies, our heterogeneous productivities of technologies introduce asymmetric changes in the marginal cost. As technologies increase in sophistication, labor productivities increase, too, which lowers the marginal costs to new firms. Hence, while the pricing rule is standard in that it represents the usual fixed mark-up over marginal cost, marginal costs and hence prices differ. Equation (6) also highlights that the amount of training, s_i, affects productivity, too. The summary result of the differential changes in marginal costs across firms is that the later the good was invented, the more productive workers are with that technology, *ceteris paribus*, and the lower the price.

Within the monopolistically competitive framework, firms pass on lower prices to consumers to capture a larger share of the market and maximize profits. Substituting (6) into (3), yields the derived demand for good i

$$x_i = \frac{e-1}{e}\frac{E(s_i^q e^i)^e}{\int_{-\infty}^{n}(s_{i'}^q e^{i'})^{e-1}\,di'} \qquad (3')$$

Clearly, market shares increase in the technological sophistication of the product. We can now combine (6), (3') (4) and (5), to find the production profits of firm i

$$p_i = \frac{1}{e}\frac{E(s_i^q e^i)^{e-1}}{\int_{-\infty}^{n}(s_{i'}^q e^{i'})^{e-1}\,di'} \qquad (7)$$

Note again that profits increase in the level of technological sophistication, so that newer technologies and goods command higher profits.

2.3) R&D

We assume with Jones (1995) and Segerstrom (1995) that the competitive research is subject to aggregate *fishing out* problems.[4] By defining $A(t)$ as the economy-wide R&D difficulty index at *t*, we can write the research function as

[4] "Fishing out" refers to the notion that easy inventions occur early with little effort. Fewer, harder problems are solved later, requiring considerably more research intensity, cost and effort. Caballero and Jaffe (1993) and Kortum (1993) provide evidence for "fishing out problems" on the industry level. The assumption also contrasts with Lai's (1998) assumption that R&D costs decline exogenously over time.

$$\dot{N} = \frac{h_R}{A} \tag{8}$$

where h_R represents the aggregate share of labor devoted to R&D at time *t*. To quantify the congestion externality, we assume that the difficulty index increases linearly in the aggregate research effort, or

$$\dot{A} = h_R \tag{9}$$

Equations (8) and (9) imply that a constant rate of innovation requires increasing amounts of effective labor devoted to R&D. Firms finance their research efforts by issuing equity and are awarded infinitely lived patents for their inventions. There is free entry into research and development. After inventing technology and after completing training, firms engage in monopolistic competition with all other patent holders.

Whenever a firm innovates, it has devoted h_{RN} units of labor to the research sector, (8), to gains the cutting edge blueprint, *N*. The cost of the research effort is the scientists' wage, h_{RN}. From the profit condition, (7) we know the instantaneous profits of a firm with technology *N*, which we can utilize to calculate the stock market value of the firm, given by the discounted net present value of the new technology:

$$V(N,t) = \int_{t+s_N}^{\infty} e^{-r(t-t)} p_N(t)dt - \int_{t}^{t+s_N} e^{-r(t-t)} h_{TN}(t)dt \tag{10}$$

The net present stock market value of the current innovator is a function of the profits that accrue to the firm using technology *N* minus the discounted value of wages paid to train h_{TN} workers for s_N periods.

Given the net present value of the blueprint as described in equation (10), a firm that invests h_{RN} units of labor for *dt* units of time, generates a value of $V(N,t)h_{RN}/A$. Free entry thus implies research will be undertaken whenever $V(N,t) \geqq A$, which constitutes the incentive condition in R&D. Since $V(N,t) > A$ implies infinite research activity, $V(N,t) = A$ must be the equilibrium condition. Free entry, thus, prevents firms from earning excess returns and relates the value of new technology to the cost of market entry. Also, as R&D difficulty increases, the value of a new technology must rise to induce positive R&D activity.

2.4) Training

The second stage of the firm's problem is to determine if and how much training should be provided, given profits derived from final good production, (7), and the cost of training h_{Ti} workers to maximize the value of any innovation. Substituting the labor demand derived from (3') and (4) into (10), the firm can determine the optimal training duration by simply maximizing *V(N, t)* with respect to s_N. Differentiating (10) with respect to s_N we find that the optimal training duration s_N^* for technology *N* is given implicitly by

$$\int_{t+s_N}^{\infty} \frac{E_{(t)} q(s_N^q e^N)^{e-1} e^{-r_{(t-t)}} (e-1)}{s_N \int_{-\infty}^{n_{(t)}} (s_{i'}^q e^{i'})^{e-1} di' e} dt - \frac{E_{(t+s_N)} (s_N^q e^N)^{e-1} e^{-r_{(s_N)}}}{\int_{-\infty}^{n(t+s_N)} (s_{i'}^q e^{i'})^{e-1} di'} - \int_{t}^{t+s_N} \frac{E_{(t)} q(s_N^q e^N)^{e-1} e^{-r_{(t-t)}} (e-1)^2}{s_N \int_{-\infty}^{n_{(t)}} (s_{i'}^q e^{i'})^{e-1} di' e} dt = 0 \quad (11)$$

where the first term represents the return to training, the second term is the cost of training and the third term represents the production profits forgone during the training period.

The positive side effect of firm-specific training is a positive spillover from firm specific training to the general pool of knowledge. Effective Labor, $h = h_p + h_T + h_R$ grows, as in Lucas (1988)[5]

$$\dot{h} = j\, h_T \quad (12)$$

where h_T represents the share of the total labor force engaged in training. The productivity parameter, j , scales the spillovers from training to the general human capital pool. Despite the spillover, however, workers are unable to use more sophisticated technology without further training.[6] The continuous increase in the level of general human capital, which drives the steady increase in effective labor, is the factor that ultimately allows for ongoing growth in our model.

The endogeneity of skills is essential to the results of the model. Recent models of non-scale growth (Jones 1995) rely on exogenous rates of population growth to determine long run growth. In our model, changes in the firms' incentives to educate endogenously

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[5] One could motivate such spillovers with intergenerational spillovers. The assumption is also convenient because it releases us from tacking each individual's employment-specific level of human capital.

[6] Training to learn a firm specific accounting program generates general familiarity with computers and accounting. However the individual still requires training if she changes jobs and works with a different firm’s more sophisticated accounting program.

alter the growth rate of effective labor (12). We show in the next section that the growth rate is indeed equal to the growth rate of effective labor, hence it is exactly the *variation* in the rate of firm specific training, due to changes in competition, for example, that translate into higher growth because skills are endogenous.

3.0) Balanced growth

Equation (11) renders the dynamic analysis about the equilibrium untrackable, hence we focus on the properties of the stationary state. Using equations (1) and (2), the consumer's problem reduces to choosing an optimal expenditure path. Solving the current value Hamiltonian for $E(t)$ renders the standard optimal condition

$$\hat{E}^* = r^* - r \tag{13}$$

where "^" superscripts denote proportional changes and "*" values represent equilibrium quantities. The absence of uncertainty renders stocks and bonds perfect substitutes in equilibrium.

3.1) Training

Using the condition for optimal training duration, (11), we employ the implicit function theorem to show that the optimal training duration is *independent* of technological sophistication,

$$\frac{\partial s_N^*}{\partial N} = 0 \tag{14}$$

This implication seems surprising at first as one might suspect that greater leaps in productivity generate more incentives for training. The intuition will become clear when we generalize the optimal training rule to

$$s_N^* = s_i^* = s^*, \tag{15}$$

which simply says that, since *all* firms possess the cutting edge technology at *some* point in time, and since the incremental increases in technology are constant along the balanced growth path, all firms train for the identical periods in equilibrium. Alternatively, equations (14) and (15) simply state that today's the cutting edge firm invests as much in training as did the cutting edge firm ten years ago. Further intuition can be derived by solving the optimal pricing rule, (6) for the training duration, $s_i = \left((e-1)p_i e^i / e\right)^{-1/q}$. The constancy of *s**, simply restates the profit maximization condition for the monopolistically competitive firm: equilibrium new firms lower the price at the rate of the productivity increase.

The stationary training decision, $s_N^* = s_i^* = s^*$, is novel in that explicit, firm-specific training is seldom introduced into growth models, especially in conjunction with and endogenous R&D decision. The fact that the training does not increase in the level of technology is, however, not a function of the model, but the prerequisite for a balanced growth path, where all variables must be stationary. If *s* were to increase in *N*, training duration would go to infinity and the share of workers trained would approach unity, because *N* increases to infinity.

Given the optimal training rule, (15), a positive return on innovation, $V[.] > 0$, implies the incentive condition $e^{-(r+g(e-1))s^*} > (e-1)/e > 0$, which imposes bounds on the market power necessary to induce the firm to invest in training. The bounds are more restrictive than in previous models of innovation *without* training, since firms must to recapture additional training costs that are absent in previous models. We assume hereafter that the condition is satisfied.

Since all new innovator firms train for equal periods in equilibrium, the number of firms that provide training in the economy at any time *t* is given by

$$S^*(t) = \int_{t-s}^{t} \dot{N}(t)dt \tag{16}$$

since the rate of technical change which is constant (and equal to the economy wide growth rate, $\dot{N}^* = g$) in equilibrium, (16) implies that the number for firms engaged in training increases in the growth rate and the training duration, $S^* = gs^*$.

3.2) Profits

Once the training duration has been established, we can rewrite the profit condition for final goods as[7]

$$p_i^* = E^*(e-1)e^{(i-n^*)(e-1)}/e \tag{7'}$$

Equation (7') immediately implies that production profits increase with technological sophistication, because the increased productivity associated with new invention generates

[7] The profit condition is similar to Caballero and Jaffe (1993), who assume that consumers value new products better by an exogenous amount. As indicated in the introduction, in our model the productivity and cost differential between firms is endogenous.

ever greater cost reductions for the current state of the art firms. This allows firms to lower the price of their product, and capture a greater market share. In addition (7') implies that the greater the number of firms involved in training at each point in time, the lower the competition in the product market, which drives up production profits. An increase in the product frontier, *n*, on the other hand, hurts profits due to the profit destruction and reduced market share, very much as in the quality ladder models.

Equation (7') clearly outlines the profit destruction and loss in market share that occurs when new goods are introduced. Since each firm's distance to the technology frontier is distinct, the introduction of new goods affects firms differently. Differentiating (7') with respect to the elasticity of substitution, we find there exists a critical technology level $\tilde{i} = n^* - (e(e-1))^{-1}$. For all firms with technologies $i > \tilde{i}$, more competition increases profits. If the firm is sufficiently far from the technology frontier, an increase in competition aggravates the impact of their high production costs, which accelerates obsolescence through profit destruction. Inevitably, each firm's technology distance to the leader widens as new products are introduced, and the technology falls below the critical level, $i < \tilde{i}$. The profit function thus features dramatic product cycle behavior, in contrast to previous variety models.[8]

The intuition to the result is that more competition allows for more substitution between goods. All goods suffer as their markup declines. However, the increased substitution allows consumers to substitute away from pricey goods towards newer, cheaper products. Hence old goods (those sufficiently far away from the technological frontier) face not only a decline in the markup, but also a decline in demand. New goods, however, find the shift in demand towards their cheaper products more than compensates for the decline in markup. The more sophisticated the technology, the lower the costs and the greater the shift in demand towards the product. Firm $\tilde{i}$ is the firm where the loss in markup equals the gain in increased demand to render profits unaffected.

3.3) Labor Markets

[8] See Lai (1997) for an alternative specification of product cycles in a product variety model.

Integrating the firms' labor demands, derived from (3') and (1), over all goods produced yields the stock of effective labor in production

$$h_P{}^* = \int_{-\infty}^{n} h_{i'}{}^* di' = \frac{E^*(e-1)}{e} \tag{17a}$$

which implies that the labor engaged in training is

$$h_T{}^* = \int_{N-S}^{N} h_{i'}{}^* di' = \frac{E^*\left(e^{S^*(e-1)} - 1\right)(e-1)}{e} \tag{17b}$$

The research equation (8), together with the incentive condition in R&D determines the number of R&D workers

$$h_R{}^* = \dot{N}^* A^* = \dot{N}^* V^*[.] \tag{17c}$$

which then implies a total labor demand of

$$h^* = h_p{}^* + h_T{}^* + h_R{}^* = \frac{E^* e^{S^*(e-1)}(e-1)}{e} + \dot{N}^* V^*[.] \tag{17d}$$

In the stationary equilibrium three conditions must be fulfilled. Labor demand must equal labor supply (12) and the proportion of labor allocated to each activity must be constant. Second, expenditures, (13), labor income, (12), and the value of the firm, (10) must grow at equal rates. Third, the amount of labor devoted to R&D and the R&D difficulty index must grow at the same rate, or $\hat{h}_R = \hat{A}$. These conditions imply

$$\hat{h}^* = \hat{h}_R^* = \hat{h}_P^* = \hat{h}_T^* = \hat{E}^* = \hat{V}^* = \hat{A}^* = \dot{N}^* = g = \frac{h_T}{h} j = \frac{j\left(1 - e^{-gs^*(e-1)}\right)(r + g(e-1))}{r + gee^{-(r+g(e-1))s^*}} \tag{18}$$

As written the growth rate is still a function of s^*. We can substitute the equilibrium conditions (15) and (13) into the optimality condition for the training duration (11) to derive the equilibrium training duration condition

$$(e-1)q - (r + g(e-1))s^* - \frac{q(e-1)^2 e^{(r+g(e-1))s^*}}{e} = 0 \tag{19}$$

which then allows us to determine s^* and g jointly. Equation (19) is in essence the individual firms' optimal training decision, given the underlying parameters of the economy. Equation (18) is the aggregate growth rate as determined by the sum of activities of all firms.

4) Properties of the Balanced Growth Path

Most noticeably, the *size* of effective labor, h, does not appear in either of the two equilibrium conditions (18) and (19). This implies that the scale of the economy does not affect long run growth, just as in the recent R&D-based growth models (e.g., Jones 1995, Segerstrom 1995, and Young 1998). The crucial difference to the previous literature is that the growth rate is not exogenous as for example in Jones, but jointly determined by the rates of investment in training and R&D. This implies that, even if R&D investment did take place, the absence of training would drive the growth rate to zero. We can summarize the characteristics of the investment in training and the growth rate with the following propositions:[9]

Proposition 1:
More competition increases both training, s, and growth, g*.*

Increased competition, as measured by an increase in the substitutability among goods, e, *g*enerates three separate effects relating to (a) labor demand, (b) training duration, and (c) profit destruction. Since increased competition allows consumers to switch more easily between goods, they substitute from expensive (old) products to cheaper (new) goods. This generates a larger market share for cutting edge firms. To satisfy the greater demand for their products, the cutting edge firms increases their labor demand. Hence more workers receive training.

Aside from the fact that more workers receive training, the increase in competition forces new innovators to re-optimize their training duration decision. For all firms with technologies $i > \tilde{i}$, more competition increases profits (7'), and the value of the firm (10) indicates that an increase in production profits compensates not only for increased training costs, but also creates greater incentives to invest in more training, which boosts productivity. As both the number of workers trained and the training duration increase, the economy wide growth rate increases, too (12).

The third effect is the profit destruction effect. As the rate of technological change increases, each firm's proximity to the technological frontier is eroded faster, (19). This implies that high tech firms lose their frontier status earlier and see their market shares dissipate sooner. This profit destruction effect reduces the incentives to train, because the time to recoup outlays has been reduced.

[9] The proofs of the propositions are provided in appendix A.

In models that abstract from training or an endogenous size of the labor force, the positive labor demand effect is offset by the profit destruction effect. This is because in such models the long run growth rate depends entirely on the R&D activity of firms seeking monopoly profit. Here, however, the positive training duration effect combines with the positive labor demand effect to dominate the adverse effects of profit destruction. Note the importance of the training component to the analysis. With exogenous population growth the economy could overcome the decreasing returns in research (see Jones 1995), but the economy would not exhibit higher growth because the factor that is used intensively in the R&D process is exogenous.

Proposition 2:

a) *Greater training efficiency, q, increases both investment in training and long run growth.*

b) *Greater spillovers from specific to general knowledge, j, increase the long run growth rate, but decrease the amount each firm invests in training.*

Greater training efficiency, *q*, increases the marginal returns to training relative to the marginal cost of training (11). As each firm trains longer, the number of firms engaged in training, S^*, rises together with the number of workers receiving training (17b). As the fraction of the labor force that receives training increases, so do the spillovers to the general human capital pool. This subsequently raises the aggregate growth rate.

Greater spillovers from specific to general knowledge increase the growth rate (18) via an increased rate of effective labor growth (12). Greater spillovers, however, also accelerate the rate of profit destruction for individual firms since new goods are introduced at a faster rate and each firm's proximity to the technological frontier erodes faster (7'). This causes each firm to train for shorter periods of time to reduce the training cost, and to start producing final goods earlier to compensate for the accelerated contraction in production profits (10). The combined effect of greater knowledge spillovers on the growth rate is positive, since the increased growth of effective labor dominates the negative effect of reduced training investment on an individual firm basis.

Since the growth rate of general human capital equals the growth rate of the economy, proposition 2b implies that an increase in the spillover parameter reduces firm-specific learning, but through the increased spillover from specific to general knowledge, the growth rate of general knowledge in the economy increases.

Proposition 3:
How the growth rate is affected by a change in the share of labor devoted to R&D, $g_R \equiv h_R / h$ *, depends on the industry characteristics or the level of development. A threshold growth rate,* $\tilde{g}$ *, determines if an increase in the share of labor increases of decreases the growth rate.*

$$\left.\frac{dg}{dg_R}\right|_{g=g^*} \begin{smallmatrix}<\\=\\>\end{smallmatrix} 0 \text{ as } g^* \begin{smallmatrix}>\\=\\<\end{smallmatrix} \tilde{g}, \text{ where } \tilde{g} \equiv \frac{r}{q(e-1)^2}$$

Proposition 3 might be the most interesting result of the model where training and R&D compete for resources, and where market power decreases the rate of growth. Conventionally product variety models have two interpretation. On the one hand the model may describe a particular industry in the economy, or it has frequently been used to describe the performance of an entire country (e.g., Romer 1990, Grossman and Helpman 1991). The Proposition adds an additional dimension, as it implies that an increase in the share or researchers devoted to R&D may increase or *decrease* the economy wide growth rate depending on whether the country is a high or a low growth country.

As the share of labor allocated to the R&D sector increases, the rate of innovation and the introduction of new goods increases, (8). This increases both the growth rate and the fishing out problem in research. From equation (16) we know that this increases the total number of firms that are engaged in training at any moment in time, which increases the share of the population that receives training, (17b) and the growth rate. However, the higher rates of innovation also have a negative impact on existing firms. The profit destruction effect increases as faster innovations and product introductions wash out the market share of yesterday's high tech firm at a faster rate. As the individual firm’s market share erodes, its training duration falls, which lowers the share of workers trained in the economy and thus the rate of general human capital accumulation and growth.

To dissect which effect dominates, we start with the case of a high growth country, $g^* > \tilde{g}$, a country with a high productivity in research, elasticity of substitution, and worker quality (see propositions 1 and 2). In this country the profit destruction effect described above is high because of the high elasticity of substitution and the high worker quality. Hence the net outcome is a decrease in the growth rate.

In the laggard, low growth country, however, where $g^* < \tilde{g}$, the low productivity in research together with a low quality work force lead to a weak profit destruction effect. In these countries a high discount rate generates a sluggish response in the training decision, and low spillovers from firm-specific to general human capital to lead to a slower increase in the rate of innovation in response to a greater research effort.

5) Conclusions

We constructed a model that incorporates costly technology absorption efforts of firms and dynamic decreasing returns to scale in R&D technology into a Schumpeterian framework to explore their implications for long run growth. The objective was to construct a model that is consistent with the empirical evidence that shows a non-monotonic relation between innovation and market power.

We propose that the main factor affecting the allocation between investment in R&D and investment in the technology absorption is the elasticity of substitution between products. Our model is capable of asymmetric effects of competition of firms. We find that more competition in product markets spurs innovation in high-tech industries, but it accelerates obsolescence for low-tech firms, those that are sufficiently large from the technological leader.

On an aggregate level, such that higher degree of substitutability may be growth enhancing if the positive effects of profit creation for high-tech firms outweigh the profit destruction experienced by laggard companies. Interestingly this translates into a non-monotonic relationship between research intensity and growth. We find that a threshold growth rate determines if higher research effort will generate positive, negative or no growth, which qualifies the strong implications regarding as scale effects in the previous R&D literature.

Our framework may be useful to examine a number of related issues. One extension may be to allow for international trade with or without imitation. We conjecture that such a model would allow for true product cycle dynamics, with dynamic changes in the production not only depending on demand and competitive conditions, but also depending on the level of human capital and time preference in a country.

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Appendix A

Properties of the Balanced Growth

Taking total differentials of equations (18) and (19), we can we find

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}\begin{bmatrix} dg \\ ds \end{bmatrix} = \begin{bmatrix} a_{13}dj + a_{14}de + a_{15}dr \\ a_{23}de + a_{24}dq + a_{25}dr \end{bmatrix}$$

$$a_{11} = g(e-1)e^{-(r+g(e-1))s}(1-gs(e-1) + \frac{(e-1)jr}{ge}\left(1-e^{-gs(e-1)}\right) - \frac{(e-1)^2 js}{g}(r+g(e-1))e^{-gs(e-1)} > 0$$

$$a_{12} = -\left[g^2 e(r+g(e-1))e^{-(r+g(e-1))} + j(r+g(e-1))g(e-1)e^{-gs(e-1)}\right] < 0$$

$$a_{13} = (r+g(e-1))(1-e^{-gs(e-1)}) > 0$$

$$a_{14} = \frac{g}{(r+g(e-1))}\begin{bmatrix} gr(1-e^{-(r+g(e-1))s}) + g^2(1+es(r+g(e-1)))e^{-(r+g(e-1))s} \\ + js(r+g(e-1))^2 e^{-gs(e-1))} \end{bmatrix} > 0$$

$$a_{15} = g^2 ese^{-(r+g(e-1))s} + g\left(\frac{j}{g}(1-e^{-gs(e-1)}) - 1\right) > 0 \quad a_{21} = -\left[(e-1)s + \frac{(e-1)^3}{e}qse^{(r+g(e-1))s}\right] < 0$$

$$a_{22} = -\left[(r+g(e-1)) + \frac{(e-1)^2}{e}q(r+g(e-1))e^{(r+g(e-1))s}\right] < 0$$

$$a_{23} = -\frac{1}{e(e-1)}\left[rs(e+1+gse(e-1)) - (q-gs)(e-1)(1+gse(e-1)\right] < 0, \text{ for } \Psi(.) > 0$$

$$a_{24} = -\left[(e-1) - \frac{(e-1)^2}{e}e^{(r+g(e-1))s}\right] < 0, \quad a_{25} = s\left[1 + \frac{(e-1)^2 q}{e}e^{(r+g(e-1))s}\right] > 0$$

The determinant, $D = a_{11}a_{22} - a_{12}a_{21} < 0$, which implies that stability in g-s space.

Proof of Proposition 1

$\frac{dg^*}{de} = \frac{1}{D}(a_{14}a_{22} - a_{23}a_{12}) > 0$. Given stability in the g-s space, $\frac{ds^*}{de} = \frac{1}{D}(a_{11}a_{23} - a_{21}a_{14}) > 0$,

Proof of Proposition 2

$$\frac{dg^*}{dq} = \frac{1}{D}(-a_{24}a_{12}) > 0, \quad \frac{ds^*}{dq} = \frac{1}{D}(a_{11}a_{24}) > 0, \quad \frac{dg^*}{dj} = \frac{1}{D}(a_{13}a_{22}) > 0, \quad \frac{ds^*}{dj} = \frac{1}{D}(-a_{21}a_{13}) < 0$$

Proof of Proposition 3

From (8'), $g_R = \left(ge(e^{-(r+g(e-1))s} - (e-1)/e)\right)/\left(r + gee^{-(r+g(e-1))s}\right)$, which implies

$$\frac{dg_R^*}{dg^*} = \frac{e(r+g(e-1))se^{-(r+g(e-1))s}}{\left(r+gee^{-(r+g(e-1))s}\right)^2}\left[\frac{r}{q(e-1)} - g(e-1)\right] \gtreqless 0.$$