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Knowledge Spillovers from Creation to Exploitation: A Theoretical Model with Implications for Firms and Public Policy

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Knowledge Spillovers from Creation to Exploitation: A Theoretical Model with Implications for Firms and Public Policy

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Abstract
In this paper we present an endogenous growth model in which we investigate the implications of knowledge spillovers between knowledge creators (inventors) and commercializers (innovators). We then turn to the question how such knowledge spillovers affect value creation within and among organizations as well as at the aggregate level and discuss how the internalization of these knowledge spillovers can help improve economic performance at both levels.

Keywords: knowledge spillovers; innovation management; strategic entrepreneurship

JEL classification: L26, O31, O32, O38

Knowledge Spillovers from Creation to Exploitation: A Theoretical Model with Implications for Firms and Public Policy

1. Introduction

The non-rival nature of knowledge was explored and identified as a key ingredient in modern endogenous growth theory (e.g. Romer, 1986). This non-rivalry opens up the possibility for knowledge spillovers between those that create knowledge and those that reap the commercial benefits from it. This possibility has attracted attention in fields ranging from technology spillovers (Coe and Helpman, 1995; Keller, 2002; Griffith et al. 2004; Cameron et al. 2005), international trade (Krugman, 1987; Feenstra, 1996), spatial agglomeration (Jaffe et al., 1993; Audretsch and Feldman, 1996; Lawson and Lorenz, 1999; Gertler, 2001), real options (Martzoukos and Zacharias, 2008), networks (Oliva and Rivera-Batiz, 1997; Carayannis et al., 2006), the evolution of industries (Niosi and Banik, 2005; Agarwal et al., 2007) and health economics (Ho, 2002).

The existing aggregate growth models, however, typically collapse invention and innovation into one decision and either stress the role of knowledge creation (e.g. idea-driven growth models following Romer, 1990; Grossman and Helpman, 1991) or new firm/product entry (e.g. the class of Schumpeterian growth models following Aghion and Howitt, 1991; Segerstrom et al., 1990).

A notable exception in the growth literature is Michellacci (2003), who presents a model of aggregate endogenous growth in which the searching and matching behavior between inventors and entrepreneurs is modeled explicitly. In his model more entrepreneurship increases the returns to knowledge creation and the other way around as more intensive search on either side speeds up the commercialization of knowledge and thereby increases the discounted return to both activities. In addition, he also introduces bargaining over the rents from innovation and explicitly allows for specialization in tasks between inventors and innovators. Michelacci's (2003) conclusions clearly underline the importance of developing and supporting both activities in tandem.

We share this conclusion; however, we arrive at it with a different set-up that is closer to the traditional innovation-driven growth models, following the narrative in the "knowledge spillover theory of entrepreneurship" as outlined in Acs et al. (2009). In our model we assume that a direct knowledge spillovers exists between knowledge creation and commercialization. In addition, we model two indirect aggregate knowledge spillovers, from knowledge creation in the past to the present, and from entrepreneurship in the past to knowledge creation in the present. This makes our results more comparable to those in endogenous growth theory but changes several of the implications for strategic innovation management at both the firm and the aggregate level.

The purpose of this paper is thus to develop a model of innovation-driven economic growth in which the role of knowledge spillovers between knowledge creation (invention) and knowledge commercialization (innovation) is made explicit. With this model we aim to study the impact of such spillovers for strategic innovation management at the individual firm and aggregate economy level.

Our contribution to the literature is twofold. Models that separate between these stages in the innovation process - invention and commercialization - are scarce and typically partial in scope, as we have argued above. Our general equilibrium innovation-driven endogenous growth model seeks to fill that gap. More importantly we are, to our knowledge, the first to introduce these well established and rigorous macro-economic modeling techniques to the field of strategic entrepreneurship, where they can help understand the interplay between micro-level innovation management and macro-level aggregate economic performance.

We conclude from our model that there is scope for efficiency enhancing innovation management strategies by internalizing direct knowledge spillovers from firm level R&D through strategic entrepreneurial ventures. Moreover, we show that the traditional form of knowledge spillover internalization, the intellectual property rights protection regime, cannot internalize all relevant spillovers and may in fact be counterproductive. Instead, we propose that the full internalization of knowledge spillovers may be achieved through a mix of strategic entrepreneurship (incumbents supporting strategic new entry and spin-outs) and intrapreneurship (incumbents exploiting new opportunities themselves) at the firm level, and policies that support both stages in the innovation process, knowledge creation and commercialization, at the aggregate level.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 discusses implications for firm and public innovation management and policy. Section 4 concludes and sets the future agenda.

2. A Model of Entrepreneurial Rents and Growth

Consider a three sector, two-factor economy in which consumers consume, save to accumulate raw capital, and supply their labor exogenously. Final goods producers produce consumption goods using labor and intermediate capital goods, invest in knowledge creation (R&D) to improve their productivity and reduce production costs. Intermediate goods producers supply them with an expanding variety of intermediate goods that are produced with raw capital, obtained in capital markets and introducing a new variety requires the input of labor resources.

The financial flows in our model can then be illustrated in Figure 1, where the arrows represent real money flows in terms of the final good that is the numeraire. Below, we introduce our notation and give the exact definition of the arrows. Then we shortly discuss the agents and discuss what problem they solve under what constraints. Finally, we discuss how the markets in the model equilibrate, before turning to an analysis of the equilibrium in the next section.

[Figure 1 about here]

Consumers

With numbers referring to the arrows in the figure, consumers have two outgoing and two incoming flows.

1. Consumption of C (at price P=1).
2. Savings $rB+wL^*$ - C, which are invested in bonds, B, yielding interest rate r.
3. Interest income rB.
4. Labor income wL^* where total labor is supplied inelastically and normalized to 1.

Consumers in our model receive interest and labor income every period and spend their income on consumption and the purchase of new bonds. They maximize a standard log-linear utility function and face a standard budget constraint:

$$\max_{C_t} : U = \int_0^\infty e^{-\rho t} \log[C_t] dt$$
$$s.t.: \dot{B}_t = w_t L^* + r_t B_t - C_t$$

where U is the utility index, ρ is the discount factor and a dot over the variable denotes time derivative.

It is a standard result that consumers will then maximize their utility by choosing consumption (and implicitly savings) in every period following the Ramsey-rule (Ramsey, 1928) such that a constant fraction of income is saved when the interest rate is constant and exceeds the discount rate (see e.g. Barro and Sala-I-Martin (2004):

$$\dot{C}_t / C_t = r_t - \rho \qquad \text{(I)}$$

Final Goods Producers

Total consumption, C, equals the sales and production, Y, of final goods producers every period as we assume the market for final goods clears instantly. The next four arrows then relate to the behavior of final goods producers, who are price takers in factor and output markets.

5. Wages wL_P where L_P is labor employed in production and w is the wage.
6. Costs of n intermediate goods $\int_0^n \chi(i)x(i)di$ bought at price $\chi(i)$ and in quantity $x(i)$.
7. R&D wages wL_R where L_R is labor employed in R&D.

8. Investment in R&D (equal to labor costs) financed in the capital market by issuing new bonds.
9. Interest payments on the stock of bonds outstanding.

For the final goods producers to have an incentive to do R&D we introduce the firm specific factor "knowledge", A, into their production function and specify the process by which they can increase that knowledge stock. Firms then choose the optimal levels of production and R&D employment and their use of intermediate goods at every point in time. Their problem is an inter-temporal one that is given by[1]:

$$\max_{L_P, x(i), L_R} : \int_0^\infty e^{-rt}\Pi = \int_0^\infty e^{-rt}\left(Y - w(L_P + L_R) - \int_0^n \chi(i)x(i)di\right)$$

$$s.t.: Y = A^\alpha L_P{}^\beta \int_0^n x(i)^{1-\alpha-\beta}$$

$$\dot{A} = \psi A^\gamma n^{1-\gamma} L_R$$

where ψ is a scaling parameter and parameters β, α and γ are the output elasticities of labor, L, and accumulated knowledge, A, in production and R&D output, respectively.

Note that we have assumed that R&D in the final goods sector receives two positive and aggregate knowledge spillovers: one from past R&D through A, and one from past entrepreneurship through the existing variety in intermediates, n. This reflects the assumption that it is easier to do R&D from an already large knowledge base and it is easier to increase productivity in the final goods sector when a lot of different specialized intermediates are available.

By the assumed symmetry and constant returns to scale specification we can study the behavior of a representative firm and solve the above dynamic optimization

[1] We have dropped the time arguments to economize on notation.

problem (see e.g. Barro and Sala-I-Martin (2004) for more details on the mathematical techniques).[2] The demand for production labor and individual intermediate variety *i* are given respectively by:

$$L_P^{\ D} = \frac{\beta Y}{w} \tag{II}$$

$$x^D(i) = \frac{\chi(i)^{\frac{-1}{\alpha+\beta}}}{\sum_{i=0}^{n} \chi(i)^{-\frac{1-\alpha-\beta}{\alpha+\beta}}}(1-\alpha-\beta)Y \tag{III}$$

The final goods sector will employ R&D workers:

$$L_R^{\ D} = \frac{\alpha \dot{A}/AY}{(r - \dot{w}/w + \gamma\dot{n}/n)w} \tag{IV}$$

as long as the wage is below the cut-off level, $\overline{w}_R$ that is given by[3]:

$$\overline{w}_R = \frac{\alpha Y \psi (A/n)^{-\gamma}}{\left(r - \dot{w}/w + \gamma\dot{n}/n\right)} \tag{V}$$

Intermediate Goods Producers

The expenditure of final goods producers on intermediates is symmetric (see equation (III)) and total expenditure is equal to the capital share in final output. There are four additional arrows into and out of the intermediate sector that exhaust the value of total sales as profits in this sector are paid out to the owners of the firms.

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[2] Even if the knowledge stock is allowed to differ among final goods producers it can be shown that only those that have $A=A^{max}$ will employ R&D workers and increase their *A* such that the firms with lower knowledge stocks will diminish.

[3] There actually is a horizontal demand curve for R&D labor due to the assumed linearity in R&D labor in the innovation function. The demand for R&D labor therefore is proportional to the growth rate of *A* in equation (IV).

10. Rental costs of the raw capital used in producing intermediate goods and financed with bonds, rK.
11. Dividends on ownership shares and /or interest on loans equal to the expected value of rents $E_0\left[\int_0^n \pi(i)di\right]$ at entry, to finance start-up investments that we assume equal the wages (foregone) by the entrepreneur (or paid to the intrapreneur).
12. Investment in entry (equal to labor costs) financed by issuing stocks and/or bonds by new entrants (or incumbent firms).
13. Labor costs of entry in intermediate sector financed by issuing stock or bonds, wL_E.

Intermediate producers are assumed to be monopolists in producing their respective varieties and they set prices to maximize their profits. A simple production technology that converts one unit of raw capital into a unit of the intermediate variety, completes the problem for the intermediate producer:

$$\max_{\chi(i)} : \pi(i) = \chi(i)x(i) - rK(i)$$
$$s.t.: x(i) = K(i) = x^D(i)$$

The intermediate goods producers then sets his price as a mark-up over marginal costs:

$$\chi(i) = \frac{r}{1-\alpha-\beta} \tag{VI}$$

As marginal costs are equal for all varieties, all varieties are priced and consequently, by equation (III), are used in final production at the same level. Given that producing a new variety yields positive profits, new entrants have an incentive to commercialize ideas for new varieties.[4] We assume that this commercialization process is costly in terms of labor and specify the entry process as:

$$\dot{n} = \varphi A L_E \qquad \text{(VII)}$$

where φ is a scaling parameter and we have assumed that new variety creation is proportional to the stock of accumulated R&D knowledge in final goods production. This reflects our assumption that R&D in final goods production generates a lot of direct knowledge spillovers in the form of new ideas and opportunities for new intermediate goods.

Below we will discuss why such spillovers are direct and create the opportunities for strategic entre- or intrapreneurial ventures. In the model, new entry is worthwhile as long as the wage is below:

$$\overline{w}_E = \frac{(\alpha+\beta)(1-\alpha-\beta)\varphi(A/n)Y}{r+\dot{n}/n-\dot{Y}/Y} \qquad \text{(VIII)}$$

and at that wages above that level, the level of entrepreneurial activity is given by[5]:

$$L_E{}^D = \frac{(\alpha+\beta)(1-\alpha-\beta)\dot{n}/nY}{(r+\dot{n}/n-\dot{Y}/Y)w} \qquad \text{(IX)}$$

To finance the labor costs of entry, new entrants issue stock or bonds and in equilibrium the profits from intermediate goods' production are exactly equal to the interest payments on bonds plus the dividend payments on stock.

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[4] One can read incumbent firms' innovation manager in lieu of new entrants and the logic of our arguments would not change. The cost to commercialize a new idea is in terms of wages and the pay-off is due to (additional) profits. Incumbent intermediate producers would have a marginally smaller incentive to enter with an additional variety, as they would compete also with their existing product lines. In large enough markets this would be a very small disadvantage and resource complementarities (not modeled here) are likely to more than offset such profit cannibalization.

[5] Again this is in fact a horizontal demand function due to the linearity of equation (VII) in labor. Both sides in (IX) are proportional to the level of entrepreneurial employment, as was the case in equation (V).

Equilibrium

The model equilibrates when all flows into and out of all the boxes add up to zero (which means agents solve their maximization problems given their constraints and do not leave any resources idle) and prices equilibrate the supply and demand on the two factor markets. It can be shown that this equilibrium exists and is both unique and stable and has positive growth in production and income.

To see this, recall that intermediate producers use a simple one-for-one technology to create their intermediates from raw, homogenous capital. As in Romer (1990) the Constant Elasticity of Substitution (CES)-production function at the final goods production stage implies that the intermediate varieties are imperfect substitutes in final goods production and thus a latent demand for all new varieties exists. The monopolists in the intermediate sector earn monopoly rents, creating an incentive for entry. Patent protection on existing intermediates might be assumed to prevent entry in the existing intermediate markets and leave entry with a new intermediate variety as the only alternative.[6] Instead one might also assume that the entrepreneur has and retains exclusive knowledge regarding his venture and competitors can never enter with perfect substitutes and drive profits to zero. [7] This implies that entry can only take place with new varieties that are imperfect substitutes.

Romer (1990) then assumes that a specialized R&D sector generates the blueprints for a new intermediate good and auctions them off to a competitive fringe of

[6] In Aghion and Howitt (1992) these entrants drive out incumbents with a higher quality version of existing varieties and entry leads to average quality improvement not to variety expansion. We acknowledge the fact that entrepreneurial activity may introduce improved versions of existing products but to keep our model tractable we follow Romer (1990) here and focus on variety expansion.

[7] Patent protection is problematic in this model as we assume that the knowledge creator is not the same agent as the knowledge commercializer. Patents are generally awarded to the knowledge creator. There is a large literature (Acs, 2008) that stresses the importance of the individual entrepreneur for the success of new ventures. His unique combination of cultural background, skills, knowledge, access to finance and other key resources and note least important, luck, makes it unlikely that any other entrant could enter the same market and drive down profits to zero by simply copying the incumbent.

potential entrants. The downstream rents thus motivate and finance an R&D sector that *generates* new ideas. The only barrier to entry in Romer (1990) is the possession of a blueprint and therefore the R&D firm, the *knowledge creator*, appropriates the full discounted rents in equilibrium. The entrepreneurial opportunity is created as a private property and commercialization is costless and automatic.

We have assumed instead that new firm entry is costly and risky and we follow Schumpeter (1911) in assuming that new opportunities are pure and costless spillovers. Therefore, the associated rents are appropriated by the entrepreneur, leaving the one that *commercializes* knowledge as the residual claimant to the monopoly rents.[8] The existence of such rents in equilibrium implies that there is a constant fraction of the labor force engaged in entrepreneurial venturing. It also implies that the rents from commercialization are not available to finance knowledge creation and no independent R&D sector as in Romer (1990) can exist in our model.

However, knowledge needs to be created somewhere and for a clear economic purpose if we wish to avoid a return to the neoclassical "manna from heaven" growth models. Large amounts of investment in corporate R&D also suggest that knowledge creation is somehow profitable to the firms undertaking it. We would argue, however, that the improvement and more efficient production of existing products is the stated aim of the corporate R&D labs we see in the world today and not the generation and subsequent auctioning off of blueprints for new (intermediate) goods as in Romer (1990). To make the generation of knowledge profitable to final goods producers in our

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[8] Although in expectation terms the profits flow back to the consumers in the Figure above, the entrepreneur, more often than not, is that specific consumer and the profits are his expected returns on foregoing labor earnings during the entry stage. We have modeled this as the entrepreneur issuing stock and bonds to finance his wage costs to reflect the fact that they take such opportunity costs into account and desire a market determined return on their investment. Alternatively, one can interpret this as an existing firm financing an entre- or intrapreneurial venture by paying those involved at least their wage.

model, these producers cannot operate under perfect competition with constant returns to scale in intermediates and labor as in Romer (1990). We assume instead that the production function has constant returns to three factors of production: labor, an aggregate of intermediates, i.e. capital, and a stock of private production knowledge.

Price taking on the demand side in labor and intermediate markets then implies that all firms have operating profits as wage and intermediates costs do not exhaust sales. This profit is the return to the firm specific knowledge stock. We assume that it needs to be accumulated prior to production so a new final goods producer must first accumulate one for himself. Free entry in final goods production will therefore not eliminate the operating profits. The stock of production knowledge can be augmented every period by doing R&D. Profit maximizing firms then choose a positive level of R&D labor that equates the discounted future value of additional operating profits to the marginal wage costs of their R&D-workers.

It can be shown that in equilibrium all firms will have the same level of production knowledge and R&D investment.[9] Our structure makes the intended outcome of R&D, efficiency gains to the firm, a pure private good of which the intended returns can be fully appropriated.[10] The markets for labor and capital connect all activities and close our model. In equilibrium we then have positive economic growth due to productivity gains in final goods production (increases in A) and variety expansion in intermediates (increases in n).

However, we also assumed that the R&D generates an accidental by-product; knowledge in the form of opportunities that the final goods producing firm does not commercialize. We also assume that final goods producing firms cannot prevent the

[9] This follows intuitively from the assumption that all final goods producing firms are equal, face the same maximization problem, production possibilities, final demand curve and set of input prices.
[10] We discuss the precise set of assumptions we need to make for this result in Acs and Sanders (2008).

spillover of that knowledge unless they enter the market with this new variety themselves.[11]

The ideas for new intermediate goods are therefore a costless knowledge spillover from incumbent firms' R&D. Ongoing R&D in incumbent firms generates a flow of ideas, some of which are commercialized and some are shelved by the incumbents for whatever reasons but then can be commercialized through new (intermediate) firm entry. In addition, we have assumed that a larger variety of intermediates increases the productivity of R&D in final goods production. This too is a costless (but indirect or aggregate) knowledge spillover. Private costs and revenues do not reflect these spillovers and hence we can derive that optimal growth requires the stimulation of either R&D or entrepreneurship.

This follows from the general theory of externalities. Any activity that generates positive externalities will be undersupplied in a market equilibrium. That general result is ameliorated in our model by the assumed positive spillover going back and forth. As R&D has a positive impact on entrepreneurship but entrepreneurship also positively affects R&D, a central planner may improve the market outcome by stimulating only the activity that is the bottleneck. The corollary to this argument implies that the positive external effect that justifies a subsidy on R&D, only materializes when entre- or intrapreneurs are present and able to commercialize knowledge spillovers. Consequently, any policy that helps R&D but hurts entrepreneurship is less effective than direct R&D stimulation and may even be counterproductive.[12]

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[11] And if there are such impediments, that would be a first target for policy. Acs et al. (2006) refer to the knowledge filter when they discuss the physical, cultural, political and institutional barriers to such knowledge spillovers.

[12] See Acs and Sanders (2008) for an application to the role of patent protection in this context.

This has a strong innovation policy implication. If we are correct in asserting that knowledge spillovers exists in both directions and specialization in the innovation chain takes place, then IPR-protection, which shifts innovation rents from the commercializer to the inventor, may reduce economic growth.

The next section elaborates on the innovation management and policy implications of the knowledge spillovers in our model.

3. Implications

Our model has implications for innovation management at different levels of analysis. First, we can consider the firms that do R&D to increase their productivity. How should they deal with the fact that such R&D may generate new commercial opportunities as an unintended side product? Then we can turn to strategic entrepreneurship as a way for these firms to enhance value creation from a given level of R&D investment. Finally, the existence of knowledge spillovers has implications for the policy maker at the aggregate level, as externalities in the market imply room for welfare enhancing government interventions.

Innovation Management

Let us first consider the implications for innovation management in final goods producing firms that do R&D with the principal aim to reduce production costs and increase productivity. In our model these firms evaluate the productivity and success of their R&D departments only and primarily on achieving that goal (by hiring R&D labor up to the point where marginal costs equal marginal *private* benefits from to productivity gains). This will lead, particularly in large firms and hierarchically organized R&D departments, to an exclusive focus on output that benefits the current rather than possible future activities of the firm. Such a strong focus gives rise to the strategic disagreements that hurt motivation and creativity and may lead to potentially very harmful spin-outs. Given the assumed co-generation of valuable commercial opportunities in our model, it makes more sense for the R&D managers to also reward the opportunities that are generated and may improve the firm's overall performance in a more dynamic sense. Firms cannot afford to pass up on such opportunities in modern, competitive, globalized and dynamic markets and increasingly seem to realize this. More room, more autonomy and broader performance measures should be implemented to motivate and manage R&D workers and teams to enhance their creativity and increase their value added for the firm. This shift in innovation management policy, however, cannot be successful in isolation. The firm also needs to develop ways to recognize and act on the opportunities generated, without jeopardizing or neglecting its existing competitive advantages.

Exploiting Commercial Opportunities

In our model a new venture is worth undertaking when the (known) discounted value of the expected profit flow exceeds the costs of labor required to set up the venture. As the incumbent producer and new entrants have the same wage costs, the same discount rate and the same expected profit flow from the venture, their decisions should be the same as well. This implies that final goods producers would simply commercialize all opportunities their R&D labs generate. The assumptions driving that result, however, are not very realistic. By relaxing them, keeping intact the structure of spillovers in our model, we can still make some informed comments on how to manage the knowledge spillovers from R&D to new firm formation.

First of all, the returns to any new venture are inherently unknown and the returns to entrepreneurial ventures are uncertain. In addition it may be hard for the creator of a new opportunity to actually convince his innovation manager of the technical and economic feasibility of his idea. The incumbent firms' managers may have good reasons to be reluctant. There are many examples that show that wild adventures may threaten the continuity of the core business. This conflict of strategic views does not imply automatically that the opportunity is lost. Studies, for example, by Klepper (2001) and Klepper and Sleeper (2005) have clearly shown that strategic disagreement among R&D workers and senior management is often the reason for so called spin-out entrepreneurship. More generally, it has been shown (Agarwal et al., 2004; Clarysse et al., 2005; Wennberg, 2008; Zhang, 2009) that new ventures spinning out of successful existing firms have a higher survival rate and performance.

From this evidence one might again conclude that the incumbent firms should commercialize all opportunities that arise in its R&D labs to internalize the positive knowledge spillover. But for every success, there are failures also. In the literature the case study methods applied and the strong survival bias in selection of the firms and industries studied may bias the general picture. In most cases the *ex ante* (perceived) risks are high and prudent innovation management requires the development of these more radical ideas outside the organization to avoid disruption to the core business.

One way of doing so is to use strategic entrepreneurial spin-out and arms-length innovation as tools in the firms' innovation strategy. To increase the value creation from given firm activity, the parent firm should aim to be the core of a cluster of related ventures that stand at a larger distance from the firm as the risks increase and the compatibility of assets is reduced. But there is definitely a strong case for the parent firm's involvement. Strategic dispute driven spin-out fails to adequately internalize the knowledge spillovers and both the entrepreneur spinning out and the parent firm could do better by managing the entrepreneurial venture strategically.

Our model, however, has little to offer on how this process is to be operationalized in detail. The many complications involved in choosing the right projects, selecting capable and motivated entrepreneurs, setting up the organization to commercialize and so forth, have all been abstracted away. Our model does show that vertical integration and knowledge sharing arrangements are better ways to internalize the direct knowledge spillovers from R&D to upstream entrepreneurial ventures, than, for example, intellectual property rights protection through patents and licensing. Practical examples of such vertically integrated innovation chains are emerging in the world and our model illustrates what underlying basic mechanism may help explain that trend[13].

The aggregate spillovers in the model, from upstream innovative entrepreneurs to downstream R&D labs and ultimately production, cannot effectively be internalized by giving individual entrepreneurs a claim on specific firms' R&D output or final product sales. The nature of the spillover is such that the collective entrepreneurial activity has a positive impact on the collective R&D effort. But such positive externalities can be internalized by knowledge sharing arrangements in the value chain. If arms-length entrepreneurial innovators share in the knowledge that is being and has been developed at the downstream firm, (such as is the case with for example IBM's

[13] Apple computers, for example, is one of the few successful vertically integrated tech companies designing its own products, controlling marketing, even selling through Apple stores. Samsung is another firm that is relatively vertically integrated yet highly profitable.

patent pool), then all entrepreneurial ventures in a firm's innovation cluster benefit from the knowledge that their activity has helped create. In an open innovation structure, where knowledge is pooled, the knowledge spillovers remain positive externalities, but they are largely offset by positive externalities that flow the other way. Both intermediate and final goods producers should realize that capitalization on the positive knowledge spillovers that they generate for others may cause a reduction of knowledge flowing in and ultimately a collapse of innovation in the value chain. But firms are not the only ones that should take policy lessons away from our model.

Public Policy

Public policy makers are interested in increasing the rate of innovation in the system as a whole (more precisely getting it closer to the optimal rate of growth). To do so efficiently they should realize that less government action is called for when knowledge flows are not inhibited. Strong protection of intellectual property rights is a policy that increases the creation and appropriation of knowledge, but does not necessarily increase commercialization and growth. In the absence of intellectual property rights, installing it is probably a good idea as knowledge creation is most likely going to be the bottleneck in innovation. But when new opportunities are accidental by-products, as they are in our model, then intellectual property rights protection may reduce the flow of ideas and rents to the commercializers and thereby also reduce the indirect but potentially important positive productivity effect on future R&D. The latter effect may offset the positive effect of higher returns to and hence higher levels of R&D activity that IPR may create.

Policies that would improve the situation unambiguously in our model will increase R&D activity or entrepreneurship without hurting the productivity of or incentives to undertake the other activity. Such policies are found in a broad range of policy domains. Reforms that enhance labor mobility between firms will increase and facilitate the flow of knowledge and arguably may even increase the productivity of R&D in generating more *recognized* opportunities for given levels of activity. It often takes some experience in an industry to see an opportunity when it presents itself. Along those lines one might also argue that educating engineers and technicians to at least consider the option of becoming an entrepreneur may stimulate the knowledge flow from R&D departments to the economy at large. Elements in labor regulation, such as the non-compete clauses, that inhibit the mobility of employees between jobs, firms and sectors should be reconsidered in light of this implication of our model.

Finally, the central government could provide general support structures for entrepreneurial activity to support the open innovation clusters of existing businesses as well as the challengers that such clusters are less likely to foster. A vibrant and well functioning market for venture capital and low regulatory and other barriers to new firm formation are high on most political agenda's (European Commission, 2000; EVCA, 2005). These policies are not straightforwardly justified using standard R&D-driven endogenous growth models, while in the context of our modified model they make perfect sense.

4. Conclusion

This paper develops a model of innovation-driven economic growth in which the role of knowledge spillovers between knowledge creation (invention) and knowledge commercialization (innovation) is made explicit. With this model we aim to study the impact of such spillovers for strategic innovation management at the individual firm and aggregate economy level.

A contribution of the paper is the introduction of a general equilibrium innovation-driven endogenous growth model that pays attention to both stages of innovation process - invention and commercialization. Along with the model the paper introduces well-established and rigorous macro-economic modeling techniques to the field of strategic entrepreneurship, which can improve the understanding of the interplay between micro-level innovation management and macro-level aggregate economic performance.

We can derive a number of interesting policy implications from our model. First, innovation management, especially in final goods producing firms, should shift from a narrow focus on improving current operations to also be attentive to potential innovations that lie outside the core business of the firm. In particular, ideas for new intermediate products and services that can be provided outside the firm should not be treated as threats but as opportunities.

Second, vertical integration and knowledge sharing arrangements with upstream suppliers are better ways to internalize the direct knowledge spillovers from R&D to upstream entrepreneurial ventures, than, for example, intellectual property rights protection through patents and licensing.

Third, the central government should shift focus from IPR-protection to direct R&D and entrepreneurship subsidies and support and should reconsider many labor market arrangements that inhibit the knowledge spillovers, particularly those at the aggregate level.

We conclude from our analysis that the full internalization of knowledge spillovers may be achieved through a mix of intrapreneurship (incumbents exploiting new opportunities themselves) and strategic entrepreneurship (incumbents supporting strategic new entry) at the firm level, and policies that support both stages in the innovation process, knowledge creation and commercialization, at the aggregate level.

Limitations of our model include in particular the deterministic way of dealing with opportunity creation and recognition. Uncertainty is essential element in entrepreneurial venturing and remains absent in our model. Also the assumed structure of knowledge spillovers remains to be validated in empirical work. The existing literature is not contradicting our assumptions, but more careful analysis is required to establish the signs and magnitudes of the important parameters in our model. These issues set an agenda for future research.

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Figure 1: Financial Flows in the model