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Promoting Innovations in Indian Universities: A Theoretical Model of University-Industry Interface

Sabyasachi Saha*

Abstract: While India's emergence as a rising economic power is an outcome of dynamic advantages based on technological learning and skills, innovation driven competitiveness has been much less prominent. It is expected that public funded institutions like universities and institutions should deliver on innovative research and ideas that can be commercialised. In this paper, we intend to understand university-industry interactions in India from a game theoretic perspective to capture issues of quality, objectives and incentives. Industry's low appetite for university inventions in India needs careful assessment, even as industry is increasingly engaging with the academia for problem solving inputs. The probability of market success of a university technology is prima facie low because these technologies are allegedly short of significant technological value addition. Often such a deficit in novelty is linked to lesser degree of complexity of research undertaken at Indian universities in the first place. Our model has indicated how various parameters like royalty fees and scientist's share of royalty and consultancy revenue could be used to promote cutting edge research at universities for technology commercialisation.

Keywords: University-Industry Interface, Technology Transfer, Innovation, India

JEL: O31, O32, O38, O39, C72

I. Introduction

While India's emergence as a rising economic power is an outcome of dynamic advantages based on technological learning and skills, innovation driven competitiveness has been much less prominent.[1] On the other hand, India still a low middle income economy and

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has enormous developmental needs. Technological capability and innovativeness plays a central role in catering to the dual need of industrial competitiveness and development. S&T in India is promoted through public funding (public funding of R&D is more than two thirds of all R&D spending) and public funded institutions (universities, advanced and specialised institutions and dedicated research organisations). It is expected that public funded institutions like universities and institutions should deliver on innovative research and ideas that can be commercialised. Poor science-industry interface, despite recent policy initiatives, continue to hold back innovations from public funded research in India. Broad policy directions alone may not influence parameters that shape innovation outcomes and their industrial application.

The potentially enormous spillover effects of academic research on commercial innovations have been adequately established in the empirical literature pioneered by Nelson (1986), Jaffe (1989) and Mansfield (1995). Cohen *et al.* (2002) use data from the Carnegie Mellon Survey on industrial R&D to evaluate the influence of "public" (i.e., university and government R&D lab) research on the US manufacturing sector and explore the pathways through which such effects take shape. They have identified the following channels of technology transfer (or sources of university information): patents, informal information exchange, publications and reports, public meetings and conferences, recently hired graduates, licenses, joint or co-operative ventures, contract research, consulting, and temporary personnel exchanges. We believe that in an evolved academic milieu research publications are encouraged through a mix of professional norms and incentives. Policy instruments are often adjusted to influence more direct modes of university-industry interactions like patenting and licensing, joint or co-operative ventures, contract research, and consulting. Other channels like public meetings and conferences, informal information exchange, hired graduates, temporary personnel exchanges, etc., help to bridge academia-industry divide.

In the context of Indian public funded research, the importance of issues like incentives for research, quality of research outcomes and motivation of universities and industry towards university-industry interface has not been studied analytically to adequately guide policymaking in this area. In advanced industrialised nations innovation ecosystems rely on pecuniary incentives for research and commercialisation. While pecuniary incentives have diminished scope under general resource constraints of a developing economy, solutions to systemic deficiencies in contexts like that of India can be best achieved through institutional reforms aimed at aligning incentives with objectives of agents like the scientist, the institution and the industry, who presumably operate in separate domains of professional demands. Game theory has been an effective tool to understand strategic interactions between agents with diverse objectives and stakes. We intend to understand university-industry interactions in India from a game theoretic perspective to capture issues of quality, objectives and incentives. This would indicate lessons for policies and instruments that shape such interactions. In our analysis, university stands for academic institutions of higher learning performing science and engineering research.[2]

After this introductory section, in Section II we lay down the conceptual framework of our analysis. Section III presents the game-theoretic model and discusses the solution method. Section IV covers analytical propositions derived from our model and Section V presents the concluding remarks.

II. Conceptual Framework

Industry research funding at universities, industry collaboration and ensuing license contracts have been studied as outcomes of strategic interactions in Jensen *et al.* (2010) and Dechenaux *et al.* (2011). We observe that these game theoretic models are broadly based on ideas that capture finer details like government versus private research funding, spillover effects from industrial consultancies, inventor participation in development and optimal license contracts, all under the assumption that core research remains the primary academic focus. This is presumably true for research environments in countries like the USA. However, in emerging economies like India university-industry interface has always remained low. Industry by and large operates on short term business models and is risk averse with respect to R&D investments. Industry research funding at universities and industry collaborations are minimal and technology transfer through licensing contracts is only sporadic. In most cases, industry relies on trouble shooting technical services of government S&T institutions. However, industry's habitual reluctance to explore university inventions for commercial development has often been linked with the quality of such inventions in terms of technological and commercial merit.

The complexity, innovativeness and success of the underlying research pursued by the scientist at the university goes a long way in determining whether it is picked up by industry and is ultimately a (blockbuster!) market success, when launched. In case of simple/ mundane/routine research undertaken by the scientist, the industry may not choose to pick up the idea as the end-product may be altogether unimpressive in terms of technological value addition with little commercial prospects. Only in case of innovative research results, obtained as outcomes of rigorous research, the industry would expect substantially high profits if they are able to commercialise it successfully. Indeed, once the end-product hits the market all the three players stand to gain. The industry gains in terms of higher profit and both the scientist and the university get their share of royalty due to technology commercialisation.

In any case, irrespective of whether or not it picks up new technological possibilities sprouting in the scientists' research, industry would require testing and trouble-shooting services from the university scientists and would engage them to obtain their technical expertise through consultancy agreements. Accordingly, we conceptualise two channels of university-industry interface: (1) the industry would almost always seek short term consultancy services and (2) they may also consider tapping university inventions for commercial development.[3]

In our framework, we consider that while both the scientist and the university are primarily driven by extra-pecuniary incentives like enhanced research profile and academic reputation, with changing times, technology commercialisation from university research has gained significant importance and this could provide the academic system with substantial pecuniary incentives in the form of license revenues. Nevertheless, any form of academic reputation and profile building for both the scientist and the university would be determined by the extent of successful completion of complex (and advanced) research projects and the quality of academic publications. Moreover, prospects of pecuniary incentives (from technology commercialisation) for the university and the scientist also stem from outcomes of advanced academic research that embody significant technological value addition. Therefore, the university has compelling reasons to incentivise scientists towards taking up core and advanced research that involves exploring complex research issues and embarking on a rigorous research agenda. We believe that such incentives take the form of providing the scientists with advanced research infrastructure, for which the university incurs substantial expenditure on research.

But at the same time, the university may also encourage industrial consultancies not only to gain in terms of financial revenue but also to build long term rapport with the industry. Although consultancy ensures a certain and definite amount of consultancy income for the scientist (shared with the university), considerably larger net pay-off from commercialisation of path breaking inventions accrue to all three players. This will clearly depend on the scientist's research time that may get squeezed due to frequent industrial consultancies. It also depends on the scientist's endeavour towards rigor while framing her core research agenda. Any 'shift' of focus away from rigorous core research towards short term consultancies is likely to slow down the growth of academic reputation of both the scientist and the university. Such 'shifts' might also reduce the chances of path-breaking innovations, in the face of inherent uncertainties associated with early stage technologies and uncertain market prospects of a new technology. Therefore, faculty members face a trade-off while balancing their research focus and the university encounters a policy dilemma![4]

Under conditions of uncertainty in research and technology commercialisation, a game-theoretic exposition of the problem would rely on expected pay-offs in a Von Neumann-Morgenstern utility framework. For ease of analysis, often a tripartite interaction of this kind is split into sequential and simultaneous moves in stages to precisely predict the behaviour of the players. In our model, we adopt a two-stage game structure similar to Jensen *et al.* (2010) to exemplify university, scientist and industry interaction as they choose optimal levels of complexity of research, research infrastructure, research time and consultancy payments to ensure maximum gains in terms of reputation, income and profit as the case may be.

III. The Model

We propose the following structure for a game in complete information with continuous pay-off and continuous strategy functions. The tripartite interaction among the three players – the university U, the scientist S and the industry I would involve both sequential and simultaneous moves in a two period game. The game is structured as follows: in the first period the play is between U and S; and in the second period between S and I. The game attempts to capture the tradeoff between uncertain but large pay-offs from core research versus assured but modest gains from consultancies from the point of view of all three players. While the university and the scientist are assumed to maximise their non-pecuniary and pecuniary gains, the industry is assumed to operate purely on a pecuniary (profit maximising) motive.

In the first period, the scientist chooses the level of rigor in her research, given university's choice of the level of funding and infrastructure meant to encourage scientists to take up more difficult research problems.[5] In the second period the industry decides per unit consultancy fee for the scientist and the scientist decides on the amount of time to be devoted to industrial consultancy depending on the consultancy fee. This determines the final outcome of research agenda and research time which shapes the prospects for research achievements (for overall academic profile) as well as commercial development and revenue gains.

In the first period of the game, both the scientist and the university ideally strive to reach higher levels of rigor in scientific research keeping in mind dual prospects of enhanced reputation and successful technology commercialisation. It is important that scientists' take up difficult research problems in the first place and the university is ready to encourage this by providing higher levels of funding and infrastructure. However, there may be a tradeoff before scientists in terms of choosing to work on complex problems vis-à-vis relatively simple ones. Working on simple problems could release some amount of professional time for undertaking industrial consultancies on a more frequent basis, driven by the attraction of an assured (but modest) financial gain.

We understand that a formidable research problem poses a considerable challenge and its successful solution is purely probabilistic. Similarly, technology transfer and its development encounter a series of uncertainties and the market success for this invention is ultimately a matter of chance. However, in case of successful completion of a complex research project, both the scientist and the university gain in terms of enhanced profile and reputation; and if this research is picked up by the industry and becomes a commercial success, both of them receive higher income as royalty share (as compared to much less consultancy revenue).

Once the level of research funding and rigor is determined in the first period, the industry and the scientist in the second period strive to attain an optimum consultancy arrangement. While the industry offers consultancy fees, the scientist decides the time to be devoted to these consultancies. They strategically interact to balance the tradeoff between modest but assured gains from consultancies with the uncertain but much larger gains from technology commercialisation.

The Pay-offs: Let us first introduce the following variables and parameters to be used as building blocks in our model.

$R_s(x)$: Scientist's reputation when she is successful in solving the chosen research problem

$R_u(x)$: University's reputation when the scientist is successful in solving the chosen research problem

x : Level of difficulty of the chosen research problem, $x \in [0, X]$

p_a : Probability that the scientist is successful in solving the chosen research puzzle

p_M : Probability that end-product based on the research result of the chosen research problem is commercially successful

v : Infrastructure spending by the university towards encouraging the scientist to take up difficult research problem, $v \in [0, V]$

t : Time devoted to industrial consultancy (If T is the total time available to the scientist, then $T - t$ is the time that the scientist employs in her core research)

c : Consultancy fee per unit time offered by the firm to the scientist

π_h : Higher profit for the firm when the end-product hits the market

π_l : Lower profit when the firm does not undertake new product development or fails in product development and maintains a low level profit with only consultancy input from the scientist

Ω : Royalty paid to the University in case the end-product based on the university technology is commercially successful

r : Rate of royalty payment

λ : Scientist's share of the royalty

$(1-\lambda)$: University's share of the royalty

γ : The share of the consultancy income retained by the scientist

$(1-\gamma)$: Proportion of consultancy income shared by the scientist with the university (overhead charges)

The probability of success for a research problem is stated as $p_a(v,t)$, which means that such a probability is determined by the scientist's effort in terms of time devoted to core research and the university's level of infrastructural funding that prompts the scientist to take up research of that level of difficulty. Therefore, with increase in both time for core research and enhanced infrastructural funding, the probability of success in tackling a research problem goes up ($\partial p_a/\partial v > 0$ and $\partial p_a/\partial t < 0$). However, the level of difficulty may be important in determining the probability of market success of the end product $p_M(x)$, where with increased x such a probability is higher ($\partial p_M/\partial x > 0$). The aforesaid probabilities are strictly concave functions in their arguments implying diminishing contributions of the variables.

University's expected pay-off depends on academic reputation, its income from overhead charges on industrial consultancies, and the share from royalty proceeds paid by the industry in case of technology commercialisation. Essentially, it depends on four variables x, v, t and c and three parameters λ, γ and r explained above. Academic reputation for a university depends on the quality of research undertaken by its faculty members. Advanced research is not only more acclaimed by the academic community, but also has the potential to bring about valuable addition to scientific knowledge and might lead to fundamental innovations. It is only natural that research problems of higher difficulty enhance the academic reputation of the university ($\partial R_u / \partial x > 0$). This also holds for the scientist's academic reputation, i.e. $\partial R_s / \partial x > 0$. The more difficult the research problem she solves the greater is she credited and recognised for her abilities. Reputation gains for an individual scientist could extend to academic awards, memberships of prestigious academic communities, fellowships, invited lectures, research grants and what not!

Pecuniary gains in terms of royalty and consultancies are shared by the university and the scientist according to stipulated norms, λ and γ, respectively. The norm of sharing (λ) of proceeds from a technology transfer and its commercialisation can be important in signalling university's willingness to adequately compensate an inventor-scientist where any higher share meant for faculty would be seen as an instrument to incentivise innovations. Royalty rate (r) on sales of the end-product to be paid by the industry to the university upon commercialisation of a university technology is negotiated between the university and the industry and is treated as given for this model.

The university's expected utility may, therefore, be written as

$$EU_u\left(x, v, t, c \middle| \lambda, \gamma, r\right) = p_a R_u(x) + p_a p_M (1-\lambda)\Omega + (1-\gamma)ct \qquad \text{.........(1)}$$

The first component on the right hand side depicts university's reputation when the scientist is successful in solving the research problem, the second component shows university's share of royalty income following commercialisation of the technology sprouting from the research result and the third component stands for university's share of consultancy revenue due to the scientist engaging in industrial consultancies.

Analogously, the scientist's expected utility is

$$EU_s\left(x, v, t, c \middle| \lambda, \gamma, r\right) = p_a R_s(x) + p_a p_M \lambda\Omega + \gamma ct \text{ ....(2)}$$

Equations (1) and (2) are explained with the help of following sign restrictions:

$p_a^{'}(v) > 0$ and $p_a^{''}(v) < 0$, $p_a^{'}(t) < 0$ and $p_a^{''}(t) < 0$, $p_M^{'}(x) > 0$ and $p_M^{''}(x) < 0$, $R_u^{'}(x) > 0$ and $R_s^{'}(x) > 0$

Utility functions for the university and the scientist in essence reflect convex preferences over pecuniary and non-pecuniary gains implying any mix of the attributes namely reputation and income is preferred to extremes.

Let us now try to understand the industry's pay-off function. Knowledge of scientific principles and experience of advanced scientific research makes academic scientists indispensable to many small and medium firms operating in technology oriented business segments. They seek to utilise this expertise for various shop-floor activities, trouble shooting, testing and monitoring through consultancy agreements. Such inputs could prove to be crucial to the industry with substantial benefits, given inadequate in-house research capabilities in certain domains of technological activity at the industry end.

Beyond such short term interface, the industry could potentially tap university inventions for commercial development. However, the industry is often reluctant to invest in early-stage university technologies, because of uncertain prospects of commercialisation. In many cases, university technologies are not even at the stage of proof-of-concept and it may just embody a technological idea. Whether such an idea solves a long-standing technological problem or is a futuristic technology solution is not clear in its nascent stage, although its potential may not be totally incomprehensible. Unsure of its future in terms of development prospects and possible uncertainties in its market run, it is likely that the industry would shy away from licensing a university technology. The only signal of vitality of such a technology could possibly be read from the complexity of research that has lead to the idea. It is here that the industry in India complains that most inventions from Indian universities are results of mundane and less-of-a-rigor research with very uncertain market prospects, if at all.[6]

In our model, the industry engages the scientist in consultancies as a matter of routine to obtain technical problem solving services from her. In case of a consultancy arrangement with the scientist, it is presumed that the industry earns a profit $\pi_l(c,t)$ (to be read as pi-low). The profit falls with increasing consultancy fees ($\pi_l^{'}(c)<0$). However, it is a monotonically increasing function of time devoted to consultancy by the scientist and hence $\pi_l^{'}(t)>0$. This implies the scientist is sufficiently incentivised through higher values of and accordingly increases her time devoted to consultancy to such an extent that the industry's profit augmentation from a higher may outweigh the profit reduction due to higher c.

However, should the industry decide to license a technology from the university for commercial development, the market success of the end-product will depend on the novelty of the idea. As elaborated, the level of complexity of the research problem underlying such an idea significantly determines its market prospects. Therefore, the probability that the end-product is a market success is $p_M(x)$; where with increased rigor of research this probability goes up however at a diminishing rate. In the event of a successful market launch of the product the firm earns a profit π_h (to be read as pi-high) which is significantly larger than π_l. The university has to be paid the pre-negotiated royalty rate (r).

Accordingly, the industry's expected profit is given as,

$$E\Pi\left(x,v,t,c \middle| \lambda,\gamma,r\right) = p_a p_M(\pi_h - \Omega) + \pi_l \qquad (3)$$

With parametric restrictions $\pi_h >> \pi_l$ and $\pi_h - \pi_l \geq \Omega$

Where $\pi_l = \pi_l(c,t)$ and $\Omega = \Omega(r)$ with signs $\pi_l'(c) < 0$, $\pi_l'(t) > 0$ and $\Omega'(r) > 0$

And as explained earlier $p_a = p_a(v,t)$ and $p_M = p_M(x)$ where, $p_a'(v) > 0$ and $p_a''(v) < 0$; $p_a'(t) < 0$ and $p_a''(t) < 0$; and, $p_M'(x) > 0$ and $p_M''(x) < 0$.

The Solution: We solve for the sub-game Nash for the second and the first period sub-games respectively. As elaborated earlier, in the second period the scientist and the industry play to reach optimal levels of consultancy time on the part of the scientist and that of the consultancy fee to be offered by the industry given the first period outcomes determining scientist's choice of the research problem with the difficulty level x and the university's level of spending on research infrastructure v. The scientist will choose her optimal time to be devoted for consultancy assignments t to maximise her expected utility as illustrated earlier. Similarly, the industry fixes the consultancy fee with the objective of maximising its expected profit. Therefore, in the second period game we should obtain the equilibrium as $(t^*(x,v), c^*(x,v))$. In the first period simultaneous move game the scientist and the university play to determine the optimal levels of difficulty of the research problem x^* and the optimal infrastructure spending v^*, respectively. Therefore, (x^*, v^*) should form the Nash equilibrium in the first period game. The pay-off functions now include the optimal levels of and obtained as second period equilibrium. The optimal behaviour of the players is obtained as reaction functions. In the second period, the scientist's reaction function is positively sloped while that of the industry is negatively sloped. In the first period, both reaction functions (of the university and the scientist) are positively slopped. We discuss the implications of our behavioural model through a standard comparative static exercise.

IV. Analysis

Effectively, from the slopes of the response functions we try to determine the directions in which the players' best response function shifts. We derive the changes in the endogenous variables induced by changes in the parameters. The set of endogenous variables include: the level of rigor in the scientist's research problem (x), the spending on research infrastructure by the university (v), the time devoted by the scientist towards consultancy (t) and the consultancy fee for the scientist to be fixed by the industry (c). The set of parameters include the stipulated revenue sharing norm between the university and the scientist for royalty incomes (λ), a similar share for consultancy revenues (γ) and the rate of royalty payment by the industry to the university (r). Accordingly, given the functional forms we get ten different comparative static results to draw certain propositions.

A. In the first period, the direction of shift of the reaction functions of the university or the scientist due to changes in royalty shares, is not unambiguous. However, changes in the norms of royalty share uniquely affect the scientist's and the industry's response in terms of the time devoted to consultancy and the consultancy fee respectively. The following two propositions would capture these effects.

PROPOSITION 1: With increase in the royalty share, the scientist tends to devote more time to core research.

Increase in the scientist's share of royalty income generated as proceeds of commercialisation of university technologies may be implemented institutionally through new norms of reward sharing between the university and the inventor scientist. With any increase in the share of royalty income, the scientist is incentivised to devote more time to core research and reduce the time she optimally devotes to consultancy assignments. In other words,

$$\frac{dt}{d\lambda} = -\frac{1}{\Delta}\left(p_M \Omega \frac{\partial^2 E\Pi}{\partial c^2} \frac{\partial p_a}{\partial t} \right) < 0 .$$

We have already argued that probability of success on a complex research problem that may lead to marketable inventions is indeed enhanced when a scientist devotes more time to core research. This also indicates that universities can possibly adopt a liberal royalty sharing norm that favours the inventor scientists by assuring them a greater share of the royalty income in order to encourage them towards core research when both parties perceive tradeoff between goals of core research and industrial consultancies.

PROPOSITION 2: With the university increasing the scientist's share of royalty income, the industry would tend to increase the consultancy fee of the scientist.

We have conceptualised that the industry's baseline profit is dependent on certain amount of consultancy services it receives from the university in the domain of testing and trouble-shooting. When the university tries to encourage the scientist towards core research by increasing her share of the royalty income, the industry must raise the consultancy fee for the scientist in order to incentivise her to continue to provide consultancy time as earlier. In other words,

$$\frac{dc}{d\lambda} = -\frac{1}{\Delta}\left(-p_M \Omega \frac{\partial^2 E\Pi}{\partial t \partial c}\frac{\partial p_a}{\partial t}\right) > 0 \text{ where } \partial^2 E\Pi / \partial t \partial c < 0 .$$

This result is driven by model assumption that irrespective of commercial exploitation of university technologies the industry has to depend on the university scientist for problem solving/trouble shooting services.

In reality, when a university wishes to promote fundamental research (and path breaking innovations) through larger share of royalty for the scientist, it may be somewhat compensated through increased earnings from industrial consultancies in terms of overhead earnings. This can happen when a fraction of university scientists are encouraged to indulge in more consultancies due to the increase in the consultancy fee paid by the industry, even as a core group of scientists respond to university's incentive and step up their research effort.

B. Although norm of consultancy share between the university and the scientist would not affect strategic response of the players in the first period, it potentially affects strategic choices of the players (the scientist and the industry) in the second period. Accordingly, we derive the two following propositions.

PROPOSITION 3: With increase in the scientist's share of consultancy revenue, she tends to optimally devote more time to industrial consultancies.

If institutional norm governing sharing of consultancy revenue between the scientist and the university is altered in favour of the scientist then the scientist is expected to be incentivised towards more consultancies. We obtain that with rising share of consultancy revenue, she tends to optimally devote more time to industrial consultancies. In other words,

$$\frac{dt}{d\gamma} = -\frac{1}{\Delta}\left(\frac{\partial^2 E\Pi}{\partial c^2} c\right) > 0 \ .$$

Universities can therefore use consultancy share as an instrument to incentivise the scientists towards any desired levels of consultancy time and hence research time.

PROPOSITION 4: With increase in the scientist's share of consultancy revenue, the industry tends to reduce consultancy fee paid to the scientist.

This result is intuitively clear and is obtained as

$$\frac{dc}{d\gamma} = -\frac{1}{\Delta}\left(-\frac{\partial^2 E\Pi}{\partial t \partial c} c\right) < 0 \text{ where } \partial^2 E\Pi / \partial t \partial c < 0 .$$

From the industry's point of view, with higher share of consultancy revenue for the scientist, the scientist can be incentivised to provide the existing levels of consultancy time with a lower consultancy fee. Hence the profit maximising industry will tend to lower the optimal consultancy fee when the university policy assures the scientist of a higher share of consultancy revenue.

C. Finally, we find that the rate of royalty payment by the industry necessarily influences the players' behaviour in equilibrium in both periods (in terms of the variables x, v, t and c) as is evident from the shifts in the best response functions. Below, we posit the following propositions.

PROPOSITION 5: With increase in the rate of royalty paid by the industry, the scientist tends to devote more time to core research.

This result is intuitively straightforward. When the industry raises the rate of royalty payments to the university, the scientist would reduce the time she devotes to industrial consultancies in favour of core research – the breeding ground for advanced and useful technologies, as the pay-off from core research increases.

Mathematically,

$$\frac{dt}{dr} = -\frac{1}{\Delta}\left(p_M \lambda \Omega^{'}(r) \frac{\partial^2 E\Pi}{\partial c^2} \frac{\partial p_a}{\partial t} \right) < 0 \,.$$

Indeed, the probability of success in a complex research problem is enhanced through devoting more time to core research and with higher financial rewards from commercialisation of a technology (royalty) the scientist is sufficiently incentivised to do so.

PROPOSITION 6: When the industry pays royalty (to the university) at a higher rate, it also increases the consultancy fee paid to the scientist.

Irrespective of the fact that the industry could explore university technologies (and those may be commercially successful), it needs to seek consultancy inputs from the scientist as is captured in its expected profit function. Therefore, in order to maintain a stable supply of consultancy services from the scientist, when the industry raises the royalty rate it has to also increase the consultancy fee. In other words,

$$\frac{dc}{dr} = -\frac{1}{\Delta}\left(-p_M \lambda \Omega^{'}(r) \frac{\partial^2 E\Pi}{\partial t \partial c} \frac{\partial p_a}{\partial t} \right) > 0 \text{ where } \partial^2 E\Pi \big/ \partial t \partial c < 0 \,.$$

The underlying logic is the similar to that of Proposition 2 – when the royalty income of the scientist increases, the industry must raise the consultancy fee for the scientist in order to incentivise her to continue to provide consultancy time as earlier. Consultancy inputs received from the scientists directly enters the industry's profit function.

PROPOSITION 7: With increase in the royalty rate, the scientist takes up more complex research problems.

In case the industry decides to license a university technology for commercial development, the market success of the end-product will depend on the novelty of the idea. As elaborated earlier, the level of complexity of the research problem underlying such an idea significantly determines its market prospects. Therefore, if the industry pays royalty at a higher rate upon commercialisation of the university technology, the scientist is indeed encouraged to engage in research problems that embody higher degree of complexity. This is shown as

$$\frac{dx}{dr} = -\frac{\Omega'(r)}{\Lambda}\left(p_a \lambda \frac{\partial^2 EU_u}{\partial v^2}\frac{\partial p_M}{\partial x} - p_M(1-\lambda)\frac{\partial^2 EU_s}{\partial v \partial x}\frac{\partial p_a}{\partial v} \right) > 0$$

where $\partial^2 EU_s / \partial v \partial x > 0$.

Therefore, when industry is interested in university research ideas for commercial development, in order to ensure that the technologies so generated at universities embodies significant technological value addition they can directly incentivise the scientists to take up advanced research by paying royalty at a higher rate.

PROPOSITION 8: With increase in the royalty rate, the university raises expenditure on research infrastructure.

When the industry pays the university a higher royalty rate the university in turn increases its expenditure on research infrastructure, which would encourage the scientists to take up complex research problems. Our conceptualisation of the university's expected pay-off justifies such shifts in the university's reaction function. This is shown as

$$\frac{dv}{dr} = -\frac{\Omega'(r)}{\Lambda}\left(-p_a\lambda\frac{\partial^2 EU_u}{\partial x\partial v}\frac{\partial p_M}{\partial x} + p_M(1-\lambda)\frac{\partial^2 EU_s}{\partial x^2}\frac{\partial p_a}{\partial v}\right) > 0$$

where $\partial^2 EU_u / \partial x\partial v > 0$.

This is an interesting result that shows that industry's willingness to favour the university with a greater share in the revenue pie generated from commercialising technologies which are based on university generated ideas pushes the university to spend more on research infrastructure. With higher royalty rates, the university foresees higher revenue and is therefore better placed to spend more on research infrastructure. This prepares a healthy ground for long term university-industry partnership when both care about taking university research ideas to the marketplace. This along with Proposition 7 suggest that when the industry is ready to share with the university larger share of the revenue due to technology commercialisation, it does not only incentivise the scientist to take up advanced research projects directly (the scientists foresee greater financial rewards), but also induces the university to spend more on research infrastructure which in turn encourages the scientist to engage in advanced research.[7]

V. Concluding Remarks

In the introduction, we had outlined the channels of university-industry interface and the modes of knowledge exchanges. University innovations entail industrial application of research outcomes generated in the universities. Promising research results, however, may not make it to the marketplace unless institutional mechanisms of university-industry interface and practices of informal interactions are in place to bridge the information gap between the university and the industry. India allegedly suffers on these counts. Specific policies have to be designed in order to promote such linkages. In our paper, we have closely looked at academic incentives, reward-sharing, and institutional channels of knowledge transfer. Appropriate mechanisms of information sharing can be useful in showcasing potential innovations to the industry. However, industry's low appetite for university inventions in India needs careful assessment, even as industry is increasingly engaging with the academia for problem solving inputs.

In so far as Indian academia is concerned, there is extreme heterogeneity in terms of research quality. The probability of market success of a university technology is prima facie low because these technologies are allegedly short of significant technological value addition. Often such a deficit in novelty is linked to lesser degree of complexity of research undertaken at Indian universities in the first place. Advanced research is considered to be a potential source of new and valuable technologies. The culture of advanced research is mostly lacking in the Indian academia even as the lack of incentives and infrastructure is seriously lamented. Our model has indicated how various parameters like royalty fees and scientist's share of royalty and consultancy revenue from the university could be used to promote cutting edge research at universities for technology commercialisation by inducing the university to spend more on research infrastructure and the scientist to choose complex and rigorous research problems and devote larger time to research.

Endnotes

1 India has traditionally demonstrated leading indigenous technological capability in strategic areas like space and defense quite unique among developing countries.

2 In India, this would include traditional universities (central and state universities), and science and engineering institutes like the Indian Institute of Technology, Indian Institute of Science, National Institute of Technology, Indian Institute of Science Education and Research, etc.,

located at various parts of the country as well as many other smaller institutions performing similar academic activities. Technically speaking we leave out specialised public funded research laboratories from our conceptual frame.

3 Santoro and Chakrabarti (2002), based on a firm level survey in the US, shows that larger (more mechanised) firms use knowledge transfer and research support avenues for competence building in non-core technological areas. By contrast, smaller firms, particularly those in high tech industrial sectors, focus more on problem solving in core technological areas through technology transfer and co-operative research arrangements.

4 See Foray and Lissoni (2010) for a detailed discussion of such dilemma both at the level of the scientist and that of the university.

5 University's role in shaping in-house research agenda is paramount given that it caters to infrastructural needs of the scientists.

6 Scientist's routine research at the university might lead to incremental and process innovations. Industry at times finds these useful and may be inclined to pursue them. Such innovations can be translated into actual industrial use with lower effort and investment. However, the scope of revenue gain (or profits) might not be very different from what the industry earns when it only relies on consultancy inputs from the university. Product innovation capabilities define a country's distance from the technology frontier. It is here that India is considered to be lagging behind. Indian universities have so far not been at the cutting-edge of scientific research that could lead to product innovations. Industry's skepticism towards university research may be read in that light.

7 Lach and Schankerman (2008) find that faculty responds to royalties both in the form of cash and research lab support, reflecting pecuniary and intrinsic research motivations, respectively.

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