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Innovation: Principles, Processes and Policy. A Review of the Contribution of *Prometheus* in its First 20 Years

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ABSTRACT *This paper reviews the contribution that* Prometheus *has made over the past 20 years to the literature on innovation, innovation policy and technological change. I offer first a necessarily subjective view of how the research literatures of innovation and innovation policy have developed in recent decades. I then compare that account with an interpretation of the emphases and trends in the corresponding areas in* Prometheus. *The research literatures involved are vast, located in many specific discipline areas and cross many discipline boundaries. While my 'home' discipline is economics I believe much can still be learned from the flexible and imaginative use of economics to frame research inquiry in the innovation area.*

Keywords: innovation, innovation policy, technological innovation, technological change, economics, *Prometheus*.

Introduction

The first appearance of *Prometheus* in 1983 coincided with a period of significant development in the analysis and understanding of technological innovation. Advances in policy analysis quickly followed as governments sought to harness emerging insights to the causes of enhanced national competitiveness and economic growth. Over the last two decades, research into innovation has continued unabated across an increasingly broad, interdisciplinary front and a rich agenda of policy experiments worldwide has helped reveal what may and may not work.

Contributions to *Prometheus* have reflected these developments somewhat unevenly. The policy-related and policy-driven conversation has, in general, outweighed theory-based exchanges though the concern of leading theorists with the strategic role of knowledge in the innovation process has been reflected in important papers in recent years.

In this paper, I offer first a necessarily subjective view of how the research literatures of innovation and innovation policy have developed in recent decades. I then compare that account with an interpretation of the emphases and trends in

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the corresponding areas in *Prometheus*. A disclaimer is in order. The research literatures involved are vast, located in many specific discipline areas and cross many discipline boundaries. My 'home' discipline is economics and I believe that much can still be learned from the flexible and imaginative use of economics to frame research inquiry in the innovation area. Innovation is a costly and competitive activity and economics is the discipline most focused on costs, incentives and market-based competition. On the other hand, I happily concede that innovation calls for acts of creativity that economics is poorly equipped to explain, induces uncertainties that challenge and sometimes defy the usual procedures of benefit–cost analysis, and involves discontinuous, lumpy change that falls outside standard marginal calculations. Other disciplines offer complementary and competing insights and a rounded understanding of the innovation process requires a multi-disciplinary approach. Had this paper been written by a sociologist, historian of technology, scientific researcher, lawyer, psychologist, management accountant, engineer, systems analyst or political scientist, it would, no doubt, have taken a different tack.

General Trends in the Literature

This section considers in turn positive analysis of the process of innovation and scholarly work on government policy for innovation.

Analysis of the Innovation Process

Leading up to the 1980s, three broad strands of analysis may be discerned in the economic analysis of innovation. First, disciples of Schumpeter[1] emphasised the turbulent, disequilibrating role of innovation in driving economic development through 'gales of creative destruction' at the levels of firm, industry and economy. Second, post-war growth theory pointed to the central importance of technological progress for maintaining long-term, continuous increases in real national income per head—but was obliged by its own technical constraints to skirt round the Schumpeterian vision and focus on equilibrium markets and steady states. Third, a huge raft of empirical analysis loosely built on the structure–conduct–performance paradigm of industry economics sought to establish connections between differences in industry structure, new technology generation (R&D spending) and indicators of success. (Some, but rather less, effort was devoted to examining the diffusion of new technology.)

In 1980, papers by Partha Dasgupta and Joseph Stiglitz[2] raised the industry-level analysis of innovation to a new level of theoretical sophistication, helping to lay foundations for the so-called New Industrial Economics and attempting to bring Schumpeterian propositions into the mainstream via game theory. The conclusions of Stiglitz–Dasgupta seemed to throw doubt on the claims of most (if not all) of the empirical work in the SCP framework. Industry structure did not determine levels of R&D, they argued: deep-seated inter-industry differences in the impact of innovation on production costs *jointly* determined differences in R&D intensity and industry structure. Re-expressed, this claim reinforced the long-standing belief that inter-industry differences in R&D effort reflected variations in technological opportunity—but with the added twist that, in addition, technological opportunity helped shape industry structure. On the other hand, the analysis predicted that variations in product demand-side factors

might also affect inter-industry differences in the outcomes of technological competition—and the extent to which firms could expect to be rewarded for innovative activity, i.e. an issue of appropriability. Technology spillovers (assumed away by Stiglitz and Dasgupta but potentially a key influence on appropriability) became the subject of extensive attention subsequently. It has since been argued that firms sometimes undertake R&D to enhance their capacity to absorb the spillovers from newly generated knowledge as much as to generate new knowledge themselves.[3]

While Stiglitz and Dasgupta claimed to have incorporated Schumpeterian propositions in their work, they relied on profit-maximising assumptions and game theoretic equilibria to obtain clear results. In 1982, Richard Nelson and Sidney Winter published their influential book *An Evolutionary Theory of Economic Change*.[4] This brought together analysis of the foundations of innovation (emphasising concepts including tacit knowledge, routines and organisational capabilities), economic growth and industry dynamics under pressure of technological competition. The work abandoned optimisation as a behavioural assumption, focused on inter-firm diversity and the idea of selection equilibrium rather than the competitive equilibrium of 'orthodox' theory, and provided the impetus for a new school of 'evolutionary economics'. Among other things, this approach also softened the distinction between the creation of new knowledge and its subsequent diffusion. All innovation draws to some extent on existing knowledge (and hence is a cumulative process giving rise to recognisable trajectories and path dependencies). Successful innovation tends to invite imitation—which, in turn, calls for local innovation to cope with deficiencies in understanding and location-specific conditions requiring adaptation.

A key motivation for the evolutionary school is to provide an account of the process of technological innovation and its connection to economic performance. At the macro-level, this link was seen as missing from post-war growth theory—which had pointed to the unique importance of technological advance in generating long term increases in real per capita incomes but had failed to provide a theory of what drove technology to change. Theorists like Paul Romer,[5] Robert Lucas,[6] and Phillipe Aghion and Peter Howitt[7] have responded to that challenge with a variety of 'endogenous' growth models, incorporating R&D, technology diffusion, entrepreneurship, and education and learning in macroeconomic models of growing economies. Debate continues on how successful this strategy has proved.

At the micro-level—the level of organisations—economists with their traditional focus on production and cost issues have neither a monopoly nor demonstrable comparative advantage over other disciplines in understanding what is going on. Nelson and Winter themselves drew extensively on the work of organisation theorists. One of the most influential developments in the broad evolutionary tradition over the last 15 years—the Resource Based Theory (RBT) of the firm[8]—relies heavily on the theory of knowledge to explain how organisations acquire and maintain the unique and non-imitable assets underpinning their competitive advantage. In many ways, RBT forms a bridge from theory that is recognisably 'economic' to the principles of corporate strategy and the strategic management of technology and innovation. Another bridge to a similar destination can be found in the work of Michael Porter,[9] starting in industry economics and building on pillars including the value chain to model the firm as a set of interrelated activities.

Managing innovation for competitive advantage has become one of the major foci of analysis in the last two decades. Should product market decisions drive technological choices, or technological innovation shape product development? What assets should organisations acquire to innovate successfully, and in what quantities? Should organisations build their own technology assets (in particular, knowledge-related assets) or should they import them—the make/buy or sourcing decision? Once firms develop technology assets of value, should they share them or protect them? As firms commit their assets to innovation, should they seek to enter markets first, or wait and see how pioneers fare? Should they focus on niche markets, or should they try to cover a field of related products?

Answering such questions required analysis of the varied environments in which innovating firms operated and contributions from a variety of disciplinary perspectives. As Pavitt[10] neatly argued, inter-sectoral variations ('science-based', 'supplier-dominated', 'production-intensive' and—later—'knowledge-intensive') reflect sectoral differences in the sources of technology, users' needs and the means of appropriating returns. The first two of these directed attention to the *connectedness* of any organisation with suppliers and users or customers (in both cases, actual and potential), the third indicated the importance of knowing how firms might use institutional and other means to *capture returns* on their innovation. The connectedness issue has led to research on the boundaries of organisations, markets versus networks, formal versus informal relationships, private–public sector links, regionally based clusters and national innovation systems. It has also underpinned much discussion around technology transfer and diffusion, nationally and across national borders. Questions about capturing returns—appropriability—are as old as patents but have recently extended to address a wide range of other legal mechanisms for intellectual property protection (copyright, trademarks, plant-breeder rights, etc). They also reach into the deep issues of competing versus collaborating on knowledge development and commercialisation, and the creation of entry barriers through pre-emptive sunk-cost investments giving access to dynamic learning economies.

The increasing emphasis on inter-organisational connections, links and relationships has inevitably invited a systems perspective on innovation analysis. While national innovation systems attracted attention initially, the dominant focus more recently has been on international systems, both within and among organisations. Technological innovation has been viewed as a major driver and facilitator of globalisation. Interdependently, the international integration of markets for intellectual and physical capital, labour and commodities are seen as accelerators and reinforcers of innovation. While innovation has a world-wide impact, however, some firms, regions and countries seem to benefit much more than others. An important debate revolves around the reasons why.

Finally, the creation and spread of new products and processes must be closely related to the commitment and productivity of certain classes of people—inventors, researchers, design engineers, entrepreneurs, gate-keepers, boundary-spanners, and others skilled in working within the knowledge economy. A growing body of literature is examining the career and incentive structures which motivate (or demotivate) such people, encourage them to operate in one place rather than another, and yield best performance.

Innovation Policy

Rationales for government involvement in the innovation process lie in the implications of various species of economic theory and the achievement of broader, non-economic goals such as national security, environmental cleanliness and public health.

Of the economic arguments, policy thinking was dominated in the early days by the 'market imperfections' approach derived from 'orthodox' neoclassical analysis: the claim that, unless certain conditions are met, the market will yield a quantity and composition of new technological knowledge and resulting outputs that are at variance with maximum social benefit. Evolutionists have offered varying views on policy. Many have contested the possibility of identifying socially optimal states of the world but, emphasising the value of experiment, nonetheless argue that a diverse range of innovation policies should be encouraged to enhance the generation of variety (new products and processes) on which competitive selection may then work. At the macro-level, endogenous long-run growth models can imply that national aggregates for R&D can be too low, compared with the social optimum. Such reasoning was embraced enthusiastically in the 1990s but has required careful adaptation to be relevant to small open economies and its implications have not always been easy to pin down in detail. Macroeconomic analysis, especially of the short-to-medium term variety, has always focused on employment outcomes and a strand of the recent literature has wondered whether 'real' technology shocks make a difference.

When non-economic goals are at stake, the argument is that some socially or politically significant outcome would be imperilled if governments failed to arrange for innovation to be undertaken. A good example would be the elements of defence research governments undertake or procure in the belief that it is essential if they are to maintain a military advantage over prospective foes. Faced with both economic and non-economic implications from innovation, policy-makers have often sought advice on priority-setting and part of the policy literature has addressed the question through setting down foundations for foresight exercises, technology forecasting and futures analysis. The broader public choice literature has relevant messages about the difficulties surrounding priority-setting exercises.

The tools of policy available to governments divide into three broad classes: directly undertaking (or procuring from private sources) research which would not otherwise have been done (influencing quantity and composition); offering subsidies or tax concessions on innovation investments such as R&D; creating institutional infrastructure to support the innovation process. Discussion around the first element has revealed 'government failure' may be as much of a threat to efficiency as 'market failure'. Debate on the second indicates we must focus on the social net value of additionally induced investment, not just gross measures of change. The last element includes facilitating trade in the use of property rights (e.g. operating a patent system) and mobilising resources to support innovation (e.g. creating a venture capital market). In all cases, on an ongoing theme is the trade-off between 'static' economic efficiency gains and 'dynamic' efficiency enhancements—a matter of much greater subtlety than is often recognised.

Good empirical policy evaluation is hard, expensive and often subject to political pressure and it has taken most of the last two decades to reach a point

where there is reasonable critical mass of results on essential questions about what works in policy and what does not. (A series of papers in *Research Policy* offered a valuable insight into what was available at the turn of the millennium.[11]) Given that the current policy focus is on improving system-wide connectedness, work in the technology transfer tradition[12] is likely to prove particularly valuable and a growing body of work is examining, qualitatively, the results of inter-institutional networking, both formally and informally. Broader analysis of 'government failure', the effects of privatisation and subsequent policy experiments on public–private sector arrangements is also highly relevant to (and occasionally based on) understanding where—institutionally speaking—R&D should be performed.

The Contributions of Prometheus

Prometheus has never really set itself up as a journal focused on theoretical analysis, but even taking that into account, the themes it has explored incorporate less than the literatures surveyed above an emphasis on developing formal theory to guide empirical research and counterbalance informal intuition. There is thus a little less than might have been expected to reflect the flavour of the big debates about how to think about and model innovation within social systems, including the economy. There are exceptions: for example, Lodewijks[13] on market structure on industrial innovation (1990); Metcalfe[14] on evolution, technology, policy and technology management (1994); Lamberton[15] with a 'Sisyphus model' of the knowledge-based economy (1997); and Howells and Roberts[16] on innovation and knowledge systems (2000). As might be apparent from the last section, these authors linked their contributions to developments triggered by the 'New Industrial Economics' (NIE), evolutionary economics (EE) and theories about the knowledge-based sources of strategic advantage linked to the tradition of resource-based theories (RBT), but for the most part, the lens of contributors has been adjusted to specific aspects of the innovation process and policy measures to shape it.

Whether the perspective is NIE, EE or RBT, the key decisions in the innovation process are made in firms. The innovation systems approach emphasises the role of other players—universities, government research agencies, linking and brokering organisations, etc. The activity of such players importantly shapes technological opportunity for profit-making firms, but transforming ideas into new products and processes widely used in society depends ultimately and unavoidably on firms, and their investment and employment decisions—whether the firms are first-to-market innovators or active participants in the diffusion process, imitating, adapting and reinventing. The tools of innovation policy used by governments significantly reflect this.

Over the years, *Prometheus* has probably had less to say about innovation and production activity *within* the firm than the topic deserves. An important conceptual paper by Mathews[17] (1989) strove to put in place new concepts to characterise flexible manufacturing technology—a happy echo of the efforts of Milgrom and Roberts in the USA at about the same time. Overall, however, the emphasis has been more on discussion at the system-wide level—including firms' relationships with other performers, sources of new ideas, determinants of appropriability, and innovation and technology flows on the national and global scale.

Among the relatively small number of papers which have sought to understand firm-level knowledge-generation activities, most have been motivated by the

observation that Australian industrial R&D is low by international standards. Lewis and Mangan[18] (1987) look for explanations in the activities of MNCs; and in an important exchange a decade later, Mitchell and Stonecash[19] (1996) and Gans[20] (1998) consider scale economies (or their absence), the pressure of research competition and the innovation incentives for overseas companies as other candidates. Soutar and McNeil[21] (1993) are more concerned with analysing success factors in West Australia's corporate innovation performance *per se*, while Sanchez[22] (1993) looks at determinants of the intensity of automation and Dwyer and Mellor[23] (1990) at product innovation activities—in both cases in Australian manufacturing industry.

Contributors have also reported research and debated issues around the corporate management of innovation, at both operational and strategic levels. Given the impact of management issues on debate in the academic research literature, one might, however, have expected a greater representation of papers in this area and in future, the journal may need to take a view on the extent to which it sees itself catering to the management community. That said, Zeleny[24] (1991) offered the view that integrated process management was a reliable, flexible method for achieving continuous quality improvement; and in an analysis unusual for drawing on Australian data, Dwyer and Mellor[25] (1992) examined links between new product strategies and performance. Fransman[26] (1994) argued that the Japanese innovation system had worked because lifetime employment arrangements had created an organisational climate conducive to innovation . . . but Nonaka, Ray and Umemoto[27] (1998) questioned in a key paper how easily the 'Japanese' management style of corporate knowledge-creation—presented as trust-based and rich in tacit knowledge transactions—might transfer to Anglo–American business environments. Strategic issues of leading and following are addressed by Lowe[28] (1997) and Hall and Densten[29] (2002). Finally, Parry[30] (1984), Vickery[31] (1986), Tisdell[32] (1990), and Hagemeister[33] (1999) look at corporate strategies for international technology transfer.

Innovating firms do not operate in a vacuum. They make strategic decisions shaped by the forces of market competition and work in an environment of public institutions, regulation, policy framed by governments past and present, and expectations of how the policy context might unfold in the future.

As noted above, not many contributors have had much to say about technological competition or the difficult corporate choices that have to be made between competition and cooperation. However, some of the implications of globalisation for competition and international trade were explored in an important issue on trade and IP guest-edited by Peter Drahos in September 1998 (Vol. 16, No. 3). Authors explored trade, competition and IP from a legal standpoint (Rothnie),[34] economic perspectives (Lamberton),[35] international trade and IP rights protection (Hall),[36] and competition over competition policy (Arup).[37] A variety of other contributors have looked at aspects of inter-organisational collaboration and clusters. These include Mandeville[38] (1988), Inkster[39] (1990), Goode[40] (1990) and Roberts[41] (1996) on the multi-function polis idea; Macdonald[42] (1983) and Cook and Joseph[43] (2001) on lessons to be drawn from the Silicon Valley phenomenon; Joseph[44] (1994) on technology parks; Liyanage and Mitchell[45] (1994) with a model of collaborative research applied to co-operative research centres; and, recently, Harman[46] (2002) with a valuable analysis of how industry-funding may affect the publication of the results of academic research.

The focus on inter-organisational links chimes well with trends in the general literature but more would be welcome on relationships among commercially oriented firms and the spectrum across the NIS from formal links (generally the most heavily studied so far) to informal links (still under-researched but recognised to be of great importance).

Firms' decisions on innovation investments and on how they frame and structure relationships with other organisations reflect to a significant extent their efforts to appropriate returns—and this relates, in part, to issues around IP and its protection. On this topic, Macdonald[47] (1989) worried that the creative juices of inventors might be sapped if governments were too generous in their protection of inventors and the same author, with Lefang[48] (1997) argued that the increasing involvement of patent attorneys in the innovation process was becoming a cause for concern. Patents are designed to encourage both the creation and diffusion of new technology—and getting the balance right is difficult. Lamberton's 1987 paper[49] presents cogent analysis of the patent reform debate while Drahos' key 1995 contribution[50] did much to shape a broader conversation about the international distribution of benefits flowing from the WTO's TRIPS agreement. *Prometheus* has also devoted space to work on IP protection beyond the patent system—MacMillan[51] (1998) and Thorpe[52] (1998) on copyright, and Rangnekar[53] (1999) on the innovation incentive value of plant breeding rights. In future, it would be good to see more on the relative importance and effectiveness of different legal instruments for appropriating returns on innovation, and a comparison of these with other and complementary means of appropriation used by commercial innovators (such as speed to market, post-sales support and confidentiality agreements).

A patent system creates a market in IP that might not otherwise exist and thus must also be seen as one of the steps governments can take to enhance efficiency by addressing 'market imperfections'. Overcoming deficiencies in market performance provides a core rationale for government policy and Joseph and Johnston[54] analysed the arguments here in a key contribution in 1985 while Metcalfe[55] (1994) has since provided a complementary evolutionary perspective. In an intriguing piece, Pandit, Swann and Watts[56] (1997) argue that the high initial marketing and consumer education costs faced by pioneering, small hi-tech firms might constitute a form of 'market failure' that is not usually recognised.

Moving from policy rationales to policy models, Lamberton[57] (1997) and Rooney and Mandeville[58] (1998) brought readers up to date with new approaches designed to cope with an economy built on exploiting (often tacit) knowledge. Mohannak[59] (1999) proposes a national innovation system model of institutional linkages that policy-makers might find useful while Winsley, Couchman and Gilbertson[60] (1998) model the possibilities for New Zealand's NIS.

There continues to be scope for debate about why policy is justified and how it might be conceptualised, for more on static versus dynamic efficiency and on market versus government 'imperfections'. Contributions would be welcome that reflect the work of public choice theorists, and trade-offs between private agent rent-seeking on the one hand and the discouragement of desirable risk-taking on the other—the stuff of regulation theory and relationships between principal and agent. To some extent, such concerns are addressed in contributions about research prioritisation, funding mechanisms and operating principles of government research agencies.

Aitkin[61] (1997) reports usefully on the 'vexed question' of setting national research priorities in Australia in the 1980s and 1990s while Turpin and Deville[62]

(1995) reflect on the research culture implications of universities and government research agencies using commercial outcomes to guide their priorities. Funding issues in basic R&D and the research of Australian universities are covered by Hanson, Steen and O'Donohue[63] (1999) and Aitkin[64] (1996), respectively. Young, Garrett and Walsh[65] (1994) ask important questions about how government research agencies (like Australia's Commonwealth Science and Industry Research Organisation—CSIRO) should set the price for research findings made available to other users—particularly in connection with commercialisation. Gunasekara[66] (2002) has explored the dilemmas around the (now-abandoned) 30% external earnings target for CSIRO.

CSIRO, with its long and distinguished history, represents a form of government-funded, research-performing institution which has become almost unique in the world. Given the relative scarcity of research on government research agencies generally, the work on CSIRO by researchers noted in the previous paragraph and by Flood[67] (1984) and Landsberg[68] (1989) is noteworthy. Parallel work reflecting the work of Australia's Defence Science and Technology Organisation (DSTO) has been done by Markowski, Hall and Dessi[69] (1997).

Other aspects of innovation-related policy to have received attention in *Prometheus* include: the generally neglected issue of relationships between state government and federal science and technology policy under federal governance (Ryan, 1991);[70] the impact of a tax concession on industrial R&D (Dwyer, 1989);[71] and—as another example of governments trying to create a market where gaps exist—the effects of a government scheme to support venture capital (Ryan, 1989, 1992).[72] Gregory[73] (1985), Enos[74] (1986), Greenwell[75] (1987), Stewart[76] (1991), and Penrose[77] (1993) have made important contributions on the broader issue of industry policy. Topical once more at the time of writing are Love[78] (1992) on the policy implications of public perceptions of risk (in relation to genetically modified organisms) and Kearton and Martin[79] (1989) on the vulnerability of technological systems to military attack and other forms of sabotage. Given advances in the general research on policy evaluation, the availability now of richer data sets across time and space, and recent developments in world events, any of these topics might reward further investigation.

Finally, employment issues. In the early days, contributions reflected concerns of the time about the potential impact of technological change on micro-level employment and industrial relations (Corina, 1983; Markey, 1987; Peet and Peet, 1987).[80] More recently, there has been a tendency to report actual outcomes: Hawke[81] (1998) on gender differences in wage returns to computer skills in Australia (females, on average, came out in front), and Engelbrecht[82] (2001) on related issues in New Zealand (where women seemed to be making a growing impact). Tsokhas[83] (1999) offered a useful analysis of a key topic, the migration of skilled labour and its regulation. Landsberg's interesting 1989 paper on CSIRO,[84] noted above, was an early contribution to the debate on managing science professionals while Randle[85] (1997) asks about the implications for professional research staff in commercial companies when the firms adopt working practices aimed at mimicking the academic environment.

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