RATIONALES FOR
SCIENCE, TECHNOLOGY AND INNOVATION POLICY

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MOTIVATION AND SCOPE

One of the most significant changes in Irish public policy in recent years has been the vastly increased priority accorded to Science, Technology and Innovation (STI). The scale of this re-orientation of policy towards the creation of a 'knowledge based society' is amply reflected in the €2.47 billion allocated to 'Research, Technological Development and Innovation' in the *National Development Plan 2000–2006*, and in the many specific initiatives within this framework. These include the €700 million Programme for Research in Third Level Institutions managed by the Higher Education Authority, the establishment of Science Foundation Ireland with a fund of €635 million, the establishment of an R&D function in the health service through the Health Research Board, the R&D support services of Enterprise Ireland, the establishment of the Irish Research Council for Science, Engineering and Technology, and the renewed emphasis on the quality and extent of scientific education in Ireland, as reflected in the Scientific and Technological Education Investment Fund, the work of the Expert Group on Future Skills Needs, and the Task Force on the Physical Sciences. The policy landscape for scientific and technological endeavour in Ireland has been transformed.

As the planning and implementation of such initiatives continues, the scope of STI policy widens, and the need to evaluate policy effectiveness assumes a greater prominence, it is timely to consider the reasoning which does, or should, motivate them.

This papers surveys economic arguments which might rationalise STI policy in Ireland. The discussion contrasts two stylised accounts of STI, the *neo-classical economics perspective* and the *evolutionary/institutional perspective*. The neo-classical perspective provides a rationale for policy intervention in the correction of 'market failures'. It is often argued that certain market failures are especially acute in STI, and in particular in the production of scientific knowledge. We therefore consider in detail the market failure represented by the underprovision of public goods, not least because this has been suggested as an important rationale for the public funding of STI activities in Ireland. When we consider evolutionary/institutional approaches, it turns out that the applicability of this concept to rationalising public policy is more nuanced that the textbook neo-classical account would suggest.

The scope of STI policy is potentially much wider than the direct provision or subsidy of research and development activities. STI policy may range over fiscal incentives and grants, human capital

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(including migration) policies and education policies, regulatory and competition policies, the framework of intellectual property rights, technology transfer and brokerage programmes, the attraction of foreign direct investment and much else besides. On the other hand, the discussion here is confined to *economic* rationales: we neglect (without disparaging) the possibility that society might wish to support STI activities for some non-instrumental reason e.g., the pursuit of knowledge for its own sake. Economic rationales for STI policy, whether neo-classical or evolutionary/institutional, are typically based on certain broad understandings of the relationships between public policy, technological progress and economic growth, and we first turn to these issues.

STI POLICY, TECHNOLOGICAL PROGRESS AND ECONOMIC GROWTH

A general economic rationale for STI policy is that we pursue it because we think it will lead to technological progress, and we think that technological progress is a crucial determinant of economic growth, which in turn we regard as ultimately vital to welfare of the individuals who comprise society.

Economic growth and welfare

By economic growth we mean continual increases in the production of marketed goods and services and in the incomes which accrue to individuals as a result of productive activities. The level of production and incomes is typically estimated by statistical aggregates such as GNP or GDP, and the rate of change in such aggregates is the growth rate (adjusting for increases in prices which do not reflect increases in real activity—thus the ‘real’ growth rate). The extent to which economic growth, understood this way, contributes to the presumed ultimate goals of policy makers—increasing the welfare of individuals in society—involves a large debate which is beyond the scope of the discussion here.[1] We simply take the desirability of growth as given, i.e., we accord it the status of a ‘primary policy objective’.

Technological progress and economic growth

We can define technological progress as the ability to produce more goods and services (output), with existing amounts of inputs (e.g., labour, capital, etc.), or equivalently, the ability to produce the same amount of output with fewer inputs. The consequences of this definition are emphasised by the economic historian Joel Mokyr in introducing his work *The Lever of Riches*:

> Technological change has been one of the most potent forces in history in that it has provided society with what economists call a “free lunch”, that is, an increase in output that is not commensurate with the increase in cost and effort necessary to bring it about. This view of technological change is inconsistent with one of the most pervasive half-truths that economists teach their students, the hackneyed aphorism that there is no such thing as free lunch. It is the purpose of this book to highlight the greatest counterexample to this statement. Economic history is full of examples of free lunches as well as (more frequently) very cheap lunches.
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> (Mokyr 1992, pp.3–4)

[1]See for example, the discussion in McAleese and Burke (2000) of growth as a policy objective in an Irish context.

A further aspect of the distinctive importance of technological progress to economic growth involves slightly more by way of economic assumptions. Economic growth can be achieved in two ways: by increasing the amount of productive inputs, (more inputs lead to more outputs), or by increasing the efficiency which with existing inputs are used i.e., by generating technological progress. The first case is often referred to as *extensive* growth, the second as *intensive* growth. Drawing on the tradition in the analysis of economic growth owed principally to Nobel Laureate Robert Solow (1956, 1957), a key argument is that there are in principle, limits to growth of the first, extensive kind, but not to the second, intensive/technologically driven growth.

For example, we may observe effective limits to the amount of labour input which can be applied to productive activities. Furthermore, labour and capital inputs may exhibit 'diminishing marginal returns'—while additional labour and capital may continue to add to total output, these increments to output decline as more and more labour and capital are added. Indeed, a central result of Solow's model is that diminishing marginal returns imply that the accumulation of capital and the addition of labour input by themselves cannot generate growth in the long-run: technological progress is the only source of sustained increases in living standards.[2]

This argument can help to characterise an economy's growth according to whether it is predominantly extensive, and thus likely to diminish, or intensive/technologically driven, and thus likely to be sustained. A lively debate within economics has considered the relative importance of extensive and intensive growth in the so-called 'Asian Tiger' economies, especially from the 1950s to the 1980s. Insofar as their growth was substantially a matter of massive capital accumulation through very high savings/investment rates in addition to rapid expansions of the labour force, and less a matter of technological progress as defined here, these countries' growth record, it is argued, hardly deserved to be termed 'an economic miracle' (Krugman 1994, Young 1995).

Ireland's status as a 'Celtic Tiger' reflects a presumed analogy with the South East Asian experience, so that this analysis has an obvious and perhaps uncomfortable resonance for us. Capital accumulation has been constrained by infrastructural bottlenecks, while continued expansion of labour supply has also presented challenges across the range of policy from taxation to immigration. Ireland is now coming to terms with the limitations of extensive growth, with the long-term prospects for sustained increases in living standards crucially dependent on technological progress.

STI policy and technological progress

Technological progress does not necessarily arise from purposeful pursuit, nor necessarily from science, and often not from policy. Nevertheless the special nature of the contribution of technological progress to growth naturally prompts a concern to arrive at a coherent understanding of the potential and limitations of public policy in this domain. The two perspectives on STI we consider here, neo-classical and evolutionary/institutional approaches, have distinctive implications for the role of policy.

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[2]For a contemporary and accessible textbook survey of models of growth, see Jones (1998). Empirical studies and surveys which examine the components of growth for a range of countries include Bassanini, Scarpetta and Visco (2000), Maddison (1987) and Fagerberg (1994).

MARKET FAILURES AND STI POLICY

Neo-classical market success and market failure

The neo-classical framework posits a theoretical ideal market as a benchmark against which real world markets are evaluated. This ideal market is characterised by the interaction through the price system of many profit-maximising private firms and many rational consumers: this is a *competitive* market. The key (and counter-intuitive) argument of neo-classical economics is that such decentralised, self-interested and unco-ordinated behaviours can lead to surprisingly coherent economy-wide outcomes—the so-called 'invisible hand' insight of Adam Smith.

Neo-classical economics advances the claim that the allocation of resources (inputs and outputs) amongst consumers and firms which results from competitive behaviour is efficient in a number of senses—for example, no re-allocation of inputs is possible which would generate more outputs, nor which would better satisfy the underlying preferences of consumers. This notion of efficiency (termed *Pareto efficiency*) is the neo-classical concept of *market success* from which we distinguish *market failure*: to the extent that real-world markets do not correspond to the ideal competitive case, they do not lead to efficient allocations of resources, and to that extent, they fail. Then policy makers have an efficiency rationale for pursuing policy interventions which correct market failures. In this framework, it would not suffice to demonstrate that "R&D leads to more and better goods and services" in order to construct a case for subsidising R&D; one would have to establish that competitive markets by themselves fail to generate the socially optimal level of R&D.

Insofar as the market failure argument is based on the desirability of efficiency, it says nothing about the role of policy in meeting other objectives. For example, technological change which creates 'winners and losers' in the labour market may be regarded as inequitable, despite its potential efficiency, thus warranting intervention on equity grounds.

The market failures which specifically characterise STI activities are typically thought to fall into three categories; indivisibilities (or scale factors), uncertainty, and the underprovision of public goods.[3]

Indivisibilities/scale factors in STI

Scientific and technological activities may require a scale of endeavour larger than competitive markets alone could generate or sustain. The capital equipment and/or instrumentation necessary for a particular project may be physically indivisible i.e., it is infeasible to scale down finely to the size of existing private firms. Larger scale may generate efficiency benefits if it permits the exploitation of specialisation in complex and multi-disciplinary research and development efforts. Also, because the outcomes of research may be highly skew-distributed (many failures, but a few extremely successful efforts), a large scale of activity may be necessary to finance the pursuit of an optimally diversified research portfolio (Sherer and Harhoff 2000).

Such considerations motivate policy interventions such as the direct financing of research, the promotion of large transnational collaborative public research projects and the facilitation of research consortia/joint ventures amongst private firms. This last option might however involve a conflict with competition policy, to the extent that firms' co-operation at the pre-competitive

[3]The following exposition draws especially upon Stoneman and Vickers (1988).

stage might later lead to efficiency-reducing collusive behaviour in the marketplace.

Uncertainty in STI

Although the very nature of knowledge production involves uncertainty, by itself this does not imply market failure since in principle, we can imagine some types of risks being traded away in markets, especially in insurance markets, in futures markets and in financial markets generally. However, as an empirical matter, markets for the range of contingencies involved in knowledge production typically do not exist to the extent necessary (if at all) to allow for the efficient allocation of resources through the price mechanism.

Furthermore, the uncertainty inherent in knowledge production may be qualitatively different from that in other domains. The neo-classical model can be extended to the analysis of situations where the values and probability characteristics of outcomes are known; economic agents are then thought of as making systematic evaluations of the future based on such probabilistic information. Yet in knowledge production, we have access neither to the value of the outcomes (e.g., the nature of new knowledge or innovative products/process) nor to their probability distributions *ex ante*, and so no reason to suppose that competitive markets will appropriately price such risks and allocate resources for knowledge production efficiently. One of the sources of this extreme uncertainty—sometimes termed 'sheer ignorance'—is that the impact of an innovation is often only apparent when it is embedded in a wider technological and socio-economic system, the dimensions of which are not perceived at the outset (because those systems are themselves partly a function of the innovation in question).

For all these reasons, there might be a role for public policy in correcting this market failure of uncertainty, perhaps especially by substituting for the failure of private capital markets to appropriately finance long-term investments in STI activities.

The underprovision of public goods in STI

That knowledge is a 'public good' and that competitive markets typically underprovide such goods is an economic argument with wide currency within the STI practitioner and policy community. This concept of a public good is best understood in contrast to the notion of a good which is implicit in the standard neo-classical model i.e., a private good.

A private good has two relevant economic characteristics on which the neo-classical claims of market success depend. First, private goods are *rivalrous in consumption* i.e., either the act of consumption is destructive (food being an obvious example) or in the case of a durable good, the act of consumption by one person precludes simultaneous consumption by another. Second, private goods are *excludable* i.e., it is feasible to prevent non-payers from enjoying the benefits of consuming the good. Rivalry in consumption ensures that the good in question is scarce relative to the demand for it, because each act of consumption requires the production of another copy of the good, or durable ownership of it; thus there is in principle a market for the good. Excludability means that producers can charge for the good through the price mechanism, so that they can appropriate some of the benefit from its provision, and so have an incentive to provide the good in the first place.

In contrast, a public good is non-rivalrous and non-excludable. Knowledge, especially in the context of STI activities, is argued to exhibit these characteristics to an acute degree. The act of using/consuming knowledge does not deplete the original quantum of knowledge (non-rivalry). Part of the non-rivalrous nature of knowledge arises from the zero or trivial marginal costs of reproducing perfect copies of electronic information goods, in contrast to the non-trivial marginal costs of producing the typical tangible private good. Furthermore, it may not be feasible to prevent non-payers from using information once produced and consequently it may not be feasible to charge for it (non-excludability)—the so-called 'appropriability problem'. If knowledge is a 'pure' public good in this sense, then the bases on which neo-classical claims for efficiency depend are absent in the 'market for knowledge'; producers cannot maintain a scarcity of the good in order to create a market, nor have they the ability to charge for it, and so poor incentives to provide it in the first place. Insofar as the provision of goods in markets depends on the responses of firms to the private benefits/cost ratio they face, and not on a social benefits/cost calculus, competitive markets in principle would appear to provide sub-optimal level of knowledge goods.

Knowledge goods may exhibit greater or lesser degrees of 'publicness' in that private firms may act, and institutions may evolve, in response to the appropriability problem in particular. Firms may seek to protect knowledge through industrial secrecy and the enforcement of intellectual property rights. Less extreme disparities between private and social benefits and costs are termed 'externalities' and/or 'spillover effects'. R&D efforts in one firm might affect the productivity of other firms in the same industry (intra-industry spillovers), or there may be such effects between technologically 'close' industries (inter-industry spillovers) or between countries through trade, foreign direct investment and human capital flows (international spillovers).[4]

In general then, this key market failure of the underprovision of public goods is taken to provide a strong rationale for STI policy, especially in the direct provision, financing and/or subsidising of the production of knowledge, whether in relation to basic scientific research or to R&D activities which are nearer the market.

A pitfall for those seeking to rely on this argument in the Irish context is that taken at face value, it implies no role for STI policy in Ireland. If scientific and technological knowledge is a public good, and given that Ireland is small in relation to the global scientific community, a rational Irish policy maker would advocate 'free riding' on the STI activities of other countries.[5] Ireland would still benefit from technological progress embodied in capital and consumer goods from abroad and from the application of what is, by assumption, costlessly reproducible new knowledge. Irish STI policy would amount to no more than free trade, a good internet connection, and a subscription to *Scientific American*.

A response to this begins with the observation that the degree of 'publicness' of scientific and technological knowledge is an empirical not an *a priori* matter. This issue has substantially informed the second (evolutionary/institutional) research agenda. We consider below research which has demonstrated that knowledge is often geographically concentrated, rather than costlessly disseminated across borders.

The above argument underlines the need to specify the institutional framework within which an economic model is presumed to apply. For example, the same basic elements of the publicness of STI knowledge can be used to construct models in which there is *overprovision* of R&D by markets; this is the case of 'patent races' in which the institutional feature of patent protection constitutes a winner-takes-all 'prize'. In such a model, many private firms are induced to engage

[4]See, for example, empirical work by Jones and Williams (2000), Bernstein and Nadiri (1988), Bernstein (1989) and Harabi (1995).
[5]Coe and Helpman (1998) present empirical estimates of R&D spillovers between countries. See also Engelbrecht (1996).

in R&D which involves the needless duplication of research projects, and inefficient multiple simultaneous discoveries/innovations (possibly at an inefficiently rapid rate, given the incentive to be first), from which only one can benefit.[6]

PROBLEMS WITH STI POLICY

Given market failures, recommending a particular policy intervention involves an assumption that the perceived benefits of action outweigh the costs. An additional assumption is that policy makers have the intention and the capacity to intervene in the desired way. Depending on institutions and the design of policy, neither assumption may be warranted. *In extremis*, the original market failures might be less serious than *public failures*, so that policy intervention might worsen outcomes overall. Such considerations, applied generally in the theory of economic policy, might be especially relevant to some aspects of STI, and we note some such possibilities below.

The marginal cost of public funds

A basic economic 'rule of thumb' for policy intervention is that we should intervene up to the point where the marginal benefit of policy matches the marginal cost. The earlier discussion on technological progress and growth suggested that the benefits of STI policy, given market failures, are potentially very great. What of the costs? The marginal cost of a policy is not fully captured by a budgetary number alone. For example, the implementation of a new environmental regulation or new intellectual property rights legislation might involve relatively minor public expenditure (mainly the salaries of those who draft and implement such measures), and at the same time have substantial wider economic effects, some of which may be negative.

In the case of the direct public funding of STI activities, an important non-obvious economic cost arises from the requirement that public expenditure be ultimately financed from taxation. Taxation imposes costs above and beyond the revenue collected insofar as taxation drives a wedge between prices paid and received in the market, thus distorting the decisions of consumers and firms, and leading to efficiency losses. The extent of this implicit cost, referred to as the *marginal cost of public funds*, depends on the design of the taxation system and its impact on the wider economy.

The opportunity cost of policies

Similarly, the budgetary cost of a policy does not fully capture marginal costs in that it does not explicitly reflect what is being foregone. What is being truly given up by a policy is the best alternative programme not funded—the 'opportunity cost'. We would like to imagine rational policy makers appropriately ranking policy options according to these sorts of costs: in practice the relevant information is extremely difficult to provide and process, and policy proceeds by less algorithmic but more pragmatic means.

Public failures in STI

The Public Choice school of thought within economics argues that economic policy advice cannot end with the identification of market failures, nor with the assessment of the costs just

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[6]The ambiguity of neo-classical results is emphasised in the survey by Geroski (1995).

discussed. We need not just a theory of how policy makers *should* behave but also an understanding of how policy makers *actually do* behave. This involves an account of policy makers' objectives, of the information they possess, of the incentives they face, and of their abilities to intervene. Such a positive (as opposed to normative) theory of economic policy has led Public Choice economists to identify a number of ways in which certain features of political decision-making mean that well-intentioned policies designed to correct market failures may generate worse outcomes than taking no policy action at all—in short, public failures.

One pervasive public failure arises because of the differential political visibility of winners and losers from any given policy intervention. For example, the beneficiaries of a subsidy are easily identified—not least by themselves—and so are more politically influential and more motivated to be active in defending their interests. The losers, even if more numerous, may be politically diffuse, especially if the losses in question are the sort of non-obvious costs identified earlier. The aggregate public failure involved here is an in-built tendency for the public sector to over-expand relative to the market economy and relative to the benefits from policy intervention.

If the extent of market failure is over-estimated, government policy might do no more than provide what the market would have provided anyway, with the additional efficiency losses discussed earlier. For example, firms might regard publicly provided or subsidised R&D as a substitute for, rather than a complement to, their own R&D activities.[7] One intrinsic difficulty for policy design is that when markets do not provide sufficient price and profit signals by which efficient resource allocation decisions can be made (i.e., when there is market failure), non-price information must be used, and this may be inadequate. Some STI policies may presume that policy makers have better information than market participants e.g., where governments perceive a failure in capital markets to 'pick winners'. Yet it is unclear why in principle the public sector would have better information on the commercial prospects of technologies than do firms: even if it did, the appropriate policy might be information dissemination, rather than subsidy. Furthermore, policy makers' objectives may not be aligned with the efficiency-enhancing goal of correcting market failures. We commit the functionalist fallacy if we imagine that because some policy measures *could* correct market failures, they *actually do* correct market failures: policy makers may have other, less lofty goals.

Public failure may arise where there are incentives for market participants to devote resources towards capturing the benefits which policy makers can deliver. This phenomenon is termed *rent-seeking*, where 'rent' is the excess private gain arising from policy interventions over and above what the competitive market scenario would involve.[8] For example, public procurement policies or technical standards regulations might deliver excess profits in this sense to certain firms. Firms have an incentive to devote resources to capturing such rents by engaging with the political process which generates them. Rent-seeking activities in principle lie along a spectrum of legitimacy, ranging from networking, lobbying and litigation all the way to corruption.

Rent-seeking in STI policy arises especially where applicants for policy-provided benefits (such as funding, subsidies and R&D tax concessions) attempt to signal compliance with the rules which public agencies set.[9] Given information asymmetries between researchers and those funding them (i.e., assuming researchers know more about their own activities than anyone else), researchers may have the option of mis-representing their work as complying with policy goals,

[7]Empirical studies of these issues include Luukokenen (1999), Guellec and Van Pottelsberghe de la Potterie (1997, 2000), and Hall and Van Reenen (2000).
[8]See for example, Baumol (1990).
[9]See the survey of the economics of science by Stephan (1996).

while in fact pursuing other research agendas. Burdensome and complicated evaluation procedures intended to ensure compliance may lead to substantial resource mis-allocation by inducing elaborate stratagems on the part of researchers seeking to capture the benefits which are in the gift of policy makers.

EVOLUTIONARY/INSTITUTIONAL PERSPECTIVES ON STI POLICY

Critiquing the neo-classical market

Critics often the regard neo-classical analysis of STI as exemplifying the general inadequacies of this dominant school of thought. The construction of a coherent alternative is no easy task, and has proceeded along many fronts. The following account is therefore a selective reflection of a multi-faceted effort, highlighting areas of greatest contrast, and distinctive implications for policy design.[10]

Any model is predicated on a demarcation between what is to be explained and what is not. In the jargon, a variable which is explained by a model is 'endogenous' to that model. An 'exogenous' variable, while it may appear in a model, is not explained by it. A number of concepts central to understanding STI activities—goods, consumer preferences, technology itself, and institutions—are exogenous to the neo-classical model. Put another way, these are 'primitive' concepts in the model, regarded as sufficiently obvious and well-defined to require little further elaboration.

Taking the concept as of a 'good' as primitive implies a great difficulty in talking about new goods—obviously of central importance in a model of innovation. Similarly, we have problems in dealing sensibly with consumer preferences for new goods, or changing/new preferences, given that in the neo-classical model, preferences are also primitive. Technology, defined as the transformation of inputs into outputs, and so technological change, are also outside the scope of explanation. Dealing with these lacunae in the mainstream model has not been a matter for evolutionary/institutional analysis alone, but it does provide a key platform for this alternative approach.[11]

Also, the institutional structure of neo-classical markets is so much a primitive concept it barely merits a mention in most text-book treatments. It is as if 'the market' could conceptually exist in an institutional vacuum, without the rule of law, or well-specified property rights. The theory of market failure, in considering a 'no-state' benchmark case, invites this interpretation. Neither is there institutional structure *within* neo-classical markets: firms are merely loci for the decisions of individual owner-manager entrepreneurs. Indeed, in the sense that in neo-classical markets all resources can be allocated via the price mechanism, firms do not exist in this model, at least not as we understand them empirically, with organisational structures and many ways of allocating resources internally other than through prices.

These deficiencies of the neo-classical school can be contrasted with an alternative attempt to take institutions seriously. This effort ranges over market and non-market institutions, and takes

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[10]Some key surveys/expositions are by Nelson and Winter (1982), Nelson (1993) Metcalfe (1995), Lundvall (1992) and Dosi (1988).
[11]Critics from the 'Austrian' school of economics have comparable concerns on these issues—see Kirzner (1997).

particular account of cultural and historical specificities neglected in the ahistorical neo-classical account.

The next level of analysis in a model involves a specification of how primitive elements interact with one another. Neo-classical analysis assumes that consumers and firms are optimizers, allowing us to focus on the properties of the end results or *equilibirium outcomes* of such optimising behaviour. In the allocation of resources which follows, there are no unexploited gains from trade, a property which leads directly to the concept of market success based on efficiency discussed earlier.

However, neo-classical analysis achieves the sharpness of its results by neglecting the underlying *dynamic processes* which generate them: it is overwhelmingly a static model. Put another way, if there are no unexploited gains from trade in this model, there is no trade. Also, since it is in the nature of equilibrium that there are no incentives for firms to change prices or quantities, it is paradoxically the case that in this model of perfect competition, the outcome is that there is no competition.

Evolutionary approaches, by varying degrees of analogy with concepts from the biological sciences, are more concerned with specifying *processes* rather than *outcomes*. This is seen as especially relevant in analysing STI activities, insofar as we take seriously the notion that such activities are intrinsically complex and uncertain. In such contexts, it is argued, the presumption of optimising behaviour on the part of consumers and firms makes little sense. The broad alternatives suggested are typically a combination of routine and adaptive learning behaviours.

This critique would apply with particular force to the role of policy makers: while the neo-classical theory of correcting for market failures conceives policy makers as rationally choosing within well-specified constraints to arrive at optimal solutions, evolutionary approaches stress that the STI environment places policy makers in much more contingent situations. Policy makers, as well as firms and consumers, deal with intrinsic complexity and uncertainty, engage in experimentation, behave adaptively, and regard their activities as involving learning, rather than the engineering of unique, stable, optimal solutions.

Re-examining knowledge

Beyond pointing to inadequacies in the neo-classical approach, the alternative evolutionary/institutional perspective offers much by way of constructive empirical insight into STI activities. In particular, the alternative approach elaborates on the concept of knowledge, a particular version of which underpins the neo-classical identification of the underprovision of public goods as a key market failure to be corrected by STI policy.

We can think of knowledge as *codified* or *tacit*. Codified knowledge can be written down, or otherwise communicated impersonally and unambiguously, and is storable. We might think of a blue-print, or a chemical formula, or the instructions for operating a piece of instrumentation, as codifiable. Tacit knowledge cannot be written down, or communicated impersonally, or stored in this way: it is knowledge which is embodied in people and networks of people, and is acquired and transmitted through experience and personal contact.

The neo-classical concept of STI knowledge as a public good assumes that the relevant knowledge is codified knowledge: thus its costless transmission and utilisation. However, empirical research points to significant tacit elements of STI knowledge, even in what might appear to be especially codifiable domains such as ‘basic science’. We might imagine that the often close relation between basic science and publicly funded university research might amplify the codifiability of the knowledge generated thereby, insofar as the incentive structure facing scientists encourages the wide, early and reproducible dissemination of results amongst a global expert community. However, some aspects of such endeavour are tacit: the rhythms and routines of research within particular sub-domains are fully absorbed not through codified artifacts such as journal articles but through the actual practice of research and through contact with the relevant networks of scientists.[12]

The role of policy revisited

To the extent that STI knowledge is more tacit and less codifiable, it has less of the characteristics of a public good than neo-classical analysis assumes. This would appear to imply that there is correspondingly less of a rationale for certain types of policy interventions e.g., direct public provision of basic research. However, while again stressing that these are empirical, not *a priori* issues, the situation even in principle is somewhat more subtle.

The economic impact of new technologies depends on their *diffusion*—the extent to which an invention or innovation is actually adopted by consumers and firms. The codifiable/public good element of STI knowledge aids this process of diffusion, and can be amenable to policy action. For example, a patent system sets up a trade-off by which innovators are allowed to appropriate private gains in return for the disclosure in the patent of the nature of the innovation and its precursors. They thereby alert other innovators to the fact that a particular technological problem is solvable and so encourage alternative innovations to the same end, even before expiry of patent rights. This suggests a role for policy makers in maximising the codifiability of knowledge, through intellectual property rights systems and information dissemination infrastructures. It has been argued that this rationale for policy activity is especially important given the enormous potential for diffusion through information and communications technologies (ICT).[13]

These considerations could also rationalise policy measures in technology transfer and brokerage, which attempt to alert firms to existing technological opportunities. To paraphrase Geroski (2000, p.623), these are policies which bring firms closer to the technological frontier, as opposed to pushing the frontier further away from them. Recent work which empirically characterises a 'European paradox' in ICT of substantial scientific endeavour co-existing with lagging commercialisation of technologies is supportive of the need for intervention of this kind (Tijssen and Wijk 1999).

That STI knowledge is partly codifiable and partly tacit emerges from empirical work which maps the geographical concentration of knowledge flows. Studies have traced linkages between basic science and nearer-to-market innovations by exploiting the data provided by patent citations of previous patents and of the scientific literature. Knowledge flows and spillovers tend to be surprisingly geographically concentrated. This has proved especially evident in empirical accounts of industry-university relationships at national and regional levels.[14] This feature of knowledge flows is one aspect of the more general tendency of STI activities to cluster in particular locations, something inexplicable by neo-classical costlessly transmissible pure public

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[12]These issues are treated in surveys by Salter and Martin (2001) and David, Mowery and Steinmuller, and are among those addressed in an Irish context in Forfás (1998).

[13]See references in Stoneman and Vickers (1988). Surveys of technology diffusion and technology transfer policy include Stoneman (1995), Sarkar (1998) and Bozeman (2000).

[14]Relevant papers include Baptista (1998), Zitt, Barr, Sigogneau and Laville (1999), Audretsch and Feldman (1996), and Jaffe (1986).

goods.

This argument restores to some extent the rationale for national STI policies, above and beyond 'free-riding' on international efforts. It also suggests that policy makers should devote explicit attention to the spatial dimension of STI activities at sub-national levels (Cooke, Uranga and Extebarria 1997). The codified/tacit distinction brings the role of human capital and education to the forefront of the policy agenda, insofar as "information is abundant: it is the capacity of absorb it which is scarce" (Salter and Martin 2001). Scientific and technological education, especially in the form of postgraduate programmes aligned to active research agendas, is one channel (migration is another). for the communication of tacit STI knowledge embodied in human capital The rationale for policy in supporting research may therefore depend less on market failures in knowledge production and more on market failures in education (e.g., the public good/externality properties of training, and missing markets for human capital).

Once we move away from the notion that technology is merely the transformation of inputs into outputs, and acknowledge the complexity of the knowledge flows involved, we are drawn to a consideration of the relationships between the various actors involved in STI. This leads to the influential concept of *systems of innovation*, comprising the various institutions involved at international, national and regional levels, both public and private, and the linkages between them (OECD 1996, Nelson 1993, Lundvall 1992, Patel and Pavitt 1994, Nasierowski and Arcelus 1999). While the term 'system' might give an unduly optimistic impression of possibilities for design and control, it does usefully raise the notion of holistic 'systemic failures' not particular to either private or public sectors, but including weaknesses in interactions between them.

A devil's advocate might observe that a recognition that institutions exist, and that they are 'complex', does not by itself advance the policy debate all that far. The hard question is how policy makers can, if at all, improve systemic performance. For example, policy makers might have a case for evaluating the quality and extent of networks of expertise, and a particular role in institution-building, taking care to permit the evolution of diverse institutional solutions in STI, and have an especial concern to facilitate linkages between actors in the STI community.

CONCLUSION

This survey has exposited some economic arguments which can motivate and rationalise public policy in an increasingly important domain. One might well anticipate that the nuances of this debate will become ever more salient in the Irish context, as STI policy moves beyond the current phase of redressing historic deficits in our research and development infrastructure, and is evaluated closely against the economic claims advanced on its behalf.

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