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In: Revue d'économie industrielle. Vol. 59. 1er trimestre 1992. pp. 222-234.

doi : 10.3406/rei.1992.1416

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RECONCILING DIVERSITY AND SCALE : SOME QUESTIONS OF METHOD IN THE ASSESSMENT OF THE COSTS AND BENEFITS OF EUROPEAN INTEGRATION

"There is no one best way the paint the Virgin ; nor is there one best way to build a dynamo toward which the design community Whiggishly gropes. Technology should be appropriate for time and place ; this does not necessarily mean that it be small and beautiful."

Thomas Hughes, 1987 "The Evolution of Large Technological Systems", in Bijker, Hughes and Pinch, "*The Social Construction of Technological Systems*", p. 68.

INTRODUCTION

The increased visibility of "evolutionary economics" in the literature over the last decade or so (1) inevitably raises questions about the potential policy impact of such work. Is such theorising destined to become an intellectual curiosity, an arena for battles between simulation modellers, or does evolutionary theorising have anything substantive to say about both general and specific policy choices ?

Evolutionary theory in biology lays much stress upon diversity. Mutations generate adaptive potential, and this resultant genetic diversity acts as a "resource pool", ensuring that unfavourable environmental changes can have a reduced impact upon the survival of a species. Variants better adapted to a changed environment will colonise areas in which changes mean they have a relative advantage.

In the realm of technology we also observe diversity in solutions to problems. The same technological problem might be interpreted in different ways by diffe-

(1) See, for example the collection in, Dosi, G et al (1988). Of more direct relevance to the role of diversity in economic evolution see also Metcalfe and Gibbons (1986), and Saviotti (1990).

rent agents, and solutions (both as hypotheses and when actually implemented) can also differ. There is also often considerable diversity evident in the institutions which are involved in making technological developments. Students of technological history recognise that diversity in both technology and institutions interacts in complex ways, (see MacKenzie and Wajcman, 1985, Hughes, 1987). These interactions are the seed bed of technological diversity.

However, it is common for economists to assume that different technological variants simply express sub-optimal configurations (perhaps due to adjustment lags) unless the diversity is readily explained by differences in factor prices, production economics and demand. In such a view, certain aspects of observed technological diversity are doubly damned : firstly, because they are technological, and therefore treated as essentially exogenous to economic analysis ; secondly, because such factors as cultural and organisational influences may have played a role in their creation. These two are areas which economists tend to treat as exogenous disturbances. As a result, the dynamics of diversity are not understood : indeed they are not readily admitted as issues which conventional economics should examine. Yet, it can be argued, technological decision-making (that is decisions made about technological choices) is not inherently unamenable to the sort of choice-theoretic analysis which economists engage in - provided that it is allowed that such choices involve the high degree of uncertainty (as opposed to quantifiable risk) which they evidently express. (We will elaborate upon this point a little later).

It is however the case at present that both the empirical existence of technological diversity and diversity in the institutions which develop these technologies, whilst being the subject of some (often anecdotal) discussion, does not attract quite the same level of interest, or of rigorous analysis, as more readily understood factors - such as scale.

By contrast, the arguments over scale economies are well rehearsed, the efficiency benefits from pursuing such economies apparently readily identifiable, and the methods of assessment quantifiable. There is as a result an imbalance in the weight given to scale economies, vis a vis diversity, in policy discussions (Geroski, 1989).

Indeed, diversity is generally identified as an obstacle to obtaining the efficiencies of exploiting scale economies. This is because whenever technological efforts are split into (potential) diversity-generating factions, the resources available for any one solution-avenue are reduced. A similar point applies to the post development stage, when different design solutions can co-exist. In short, there are potential economies of scale associated with concentrating upon a lower number of technological variants.

However, there is a potential trade-off between what we shall loosely term "economies of diversity" and conventional "economies of scale". What we call economies of diversity occur both in consumption and production. In consumption the availability of a greater rather than a lesser range of goods must, assuming that consumers "preferences for goods" characteristics differ, satisfy more wants for any given set of preferences. (This is the point made by Geroski). In production, we will argue, there are also potential efficiency gains to be realised from the existence of diversity in technologies (including organisational technologies). Both potential sources of welfare gain may be lost to the extent that increased industrial concentration brings with it a homogenisation of technologies.

This trade-off is not a mere theoretical curiosity, it is the source of real policy dilemmas. Government, either through direct procurement, or through regulatory policy, inevitably does something to direct the precise directions taken by technological advance. Indeed, arguments concerning the increase in the rate of technical change per se have been important in formulating policies involving deregulation and increased competition. Equally, decisions made by government or shaped by political cultures have been influential in determining both the structures of industries and their choices of technology. Such choices have brought about much of the diversity in specific sectors.

However, whilst arguments about economies of scale are familiar to policy-makers, arguments which refer to the existence of economic benefits from diversity, though of recognised importance in certain areas, are more nebulous and theoretically underdeveloped (2). We will suggest that a consideration of the possibility of economic benefits arising from diversity ought also to play an explicit role in any policy area in which the rate, and direction, of technical change is an important variable.

The purpose of this article is to examine the potential for developing an analysis of the mechanisms which *generate* technological diversity, and to discuss the policy trade-off between exploiting economies of scale and exploiting the "economies of diversity" which can exist when different technological solutions and trajectories are fostered.

The paper is organised as follows. In the next section we discuss in a little more depth the relationship between diversity and scale. We follow this with a discussion of the conception of technological decision-making which we should adopt if we are to improve our analysis of the forces which generate technological diversity. We will argue here that technological decision making must be analysed, in part, as reflecting social choices within perceived technological constraints rather than being seen as pure technological optimisation - which is an unlikely case, especially where complex design choices are faced. Such an analysis will enable us to understand the ways in which different organisational structures and cultural factors influence technological development, and hence generate technological diversity.

THE DIMENSIONS OF DIVERSITY AND SCALE

It is not uncommon to encounter references to diversity, often directly related to scale, in the literature on the economic benefits of European integration. For example Geroski (1989) argues that product diversity is likely to increase with increased European integration, and that this is a good thing (using the satisfaction of wants argument noted above). He adds that, as a result, not all the hypo-

(2) One notable exception was presented precisely in the context of assessing the Single European Market. See Geroski (1989).

thesised scale-driven economies will be realised, and that they may in any case be over estimated. He cites cases of past failures of government sponsored "rationalisations" aimed at achieving economies of scale as evidence of the dangers of scale-prioritised policies (3). As Gatsios and Seabright point out,

"It is hard to know in advance whether the Single Market will lead mainly to scale gains, mainly to diversity gains, or to some combination of the two. But there is no particular reason to think that the process of integration will lead Europe naturally to the optimum point on the new scale-diversity frontier". (Gatsios and Seabright, 1989 p. 38).

It is important to stress however that "diversity" is taken by these authors solely to mean *product range* not diversity at the level of the processes which produce these products. It is closely related to the notion of economies of scope. All other things being equal, the range of product variants we observe in the market will reflect industry-specific trade-offs between scale and scope, matched with changes in demand preferences, together with any regulatory and market-distorting influences. Setting the latter two inter-related factors aside, it is generally taken to be the case that unless overheads (such as R&D) are spread over product ranges (eg. automobile body shell development efforts used by a number of different model variants around that body shell) scale factors (in this case cumulative model production volume) will mitigate against product diversity. It is only when purchasers are prepared to pay more for exclusivity that the higher unit production costs of lower cumulative production volumes are viable. Similar arguments apply to scale economies of the batch size type (in this case lower set-up costs allow smaller economic batch sizes and hence more "flexible" production, able to target smaller market niches).

These are dimensions of diversity which are comparatively easily related to scale economies because they are analytically derivable *from* scale effects. Given variations in purchasers' preferences for product characteristics, this type of product diversity is simply the diversity which can be sustained at given factor and product prices *given* a particular configuration of scale economies. This is akin to 1-s, where "s" are scale effects (of whatever type). Holding everything else constant if "s" gets weaker (eg cheaper R&D costs per unit of notional R&D output) then the residual (diversity) effect gets stronger.

TECHNOLOGICAL DIVERSITY AND TECHNOLOGICAL CHOICES

There is however another aspect to diversity which though related to the above is not derivable from scale in the above "accounting identity" sense. This is technological diversity on the supply side. Even when factor prices and production technologies and economies are identical, agents characteristically exhibit diversity in the way in which they appraise technological problems and the responses to these problems which they arrive at. This is readily explainable, in part, as a product of high risk and uncertainty, evaluated differently by different actors, and of different institutional structures and histories (if knowledge is not a free

(3) For example the formation of British Leyland in 1968, which produced a 'national champion' set to decline producing a reduced number of vehicle models of poor quality and with little exploitation of assumed scale economies, (Geroski, 1989, p. 37).

good - which it is not). Technological decision-making is sufficiently complex and "open" that it may not be clear even what risks and payoffs should be assigned to different options, (especially if the planning horizon goes beyond the several such sequential decision problems). In other words the same design problem (representable as a complex trade-off space) can be interpreted in different ways by agents. More innovative agents will explore (purely by definition of being more innovative) solutions which are less explored by competitors, even if there are generally held perceptions (technological trajectories) of which performance variables are more important. For example, even though the general technological trajectories in semiconductor design are now clearly established, and rather narrow, the innovations involved in developing "reduced instruction set" (RISC) microprocessors required that a different route to the same overall design objective was pursued (4). The fact that researchers at IBM developed the basics of RISC architecture, though IBM failed to develop the innovation because it had so much invested in existing complex instruction set architectures and software, illustrates the fact that there may be nothing inherent in large corporations which limits unorthodox solutions to technological problems, rather, it can be readily understandable features of existing investments which select against such innovations.

The point is then that there is a subjective (perceptual) dimension to technological decision making, which means that as long as there are different groups of actors competing around similar (even identical) technological problems, a diverse set of solutions may emerge. This argument, and its relationship to treatments of rationality is developed further in Farmer and Matthews, (1991). It is important to stress that the need to look at such factors as "national/regional and firm cultures" in influencing technologies' development, obviates the need to rely upon stochastic factors as diversity-generating mechanisms.

We would argue that the present reliance upon stochastic processes by evolutionary economists (see for example Nelson and Winter, 1982), though close to theoretical work in evolutionary biology (from which techniques can therefore be borrowed) is the single biggest obstacle which prevents an adequate theorising of diversity generating mechanisms. The essence of these, in the real world of R&D labs and production facilities, are purposive searching, heavily influenced by non-technological considerations. To the extent that good social science involves claims about real existing mechanisms, the use of stochastic proxy variables substitutes for decidedly non-stochastic real processes, (save for certain types of R&D in a limited number of industries such as pharmaceuticals, in which existing compounds are picked, more or less, at random and their effects ascertained).

The numerical simulation models being developed in evolutionary economics at present may do something to reveal the macro properties of systems based on certain types of initial condition states and selection mechanisms. But they will do little to inform policy unless they recognise the need to be able to better analyse particular micro phenomena (eg. a particular aircraft design) as the product of overwhelmingly non-stochastic processes. Such research is likely to be closer to critical and deconstructionist analyses of architecture and design, in which sub-theories are developed about technical, economic and stylistic influences upon par-

(4) In this case optimising chip design for the most frequently used (simple) operations and carrying out (less frequent) more complex operations via software rather than by hardware.

ticular features, than to natural scientific analyses of the behaviour of particles subject to disturbances, even when these are path-dependent and constitutive of entities subject to self-organising processes. (See Prigogine and Stengers (1985) for an accessible account of the "new" non-linear thermodynamics, and Silverberg, Dosi and Orsenigo (1988) for the flavour of more recent modelling in evolutionary economics).

Technological competition need not necessarily be reduced as the number of market-delineated players is reduced, so long as each player retains, or develops, mechanisms for fostering internal competition, for example between different R&D laboratories. This competitive arena, which yields valuable technological diversity at the R&D stage, need not rely upon competition across market boundaries. It can be a feature of internal organisation. However, the internal duplication of R&D activities will tend to provide a focus for cost-cutting within the corporation. The corporation is not naturally subject to mechanisms which cause it to value the long term social benefits of technological diversity. Hence it is possible that the social benefits of maintaining the sources of technological diversity will be far greater than the private benefits, but that the more limited portfolio of technological solutions will prevail in a competitive and unregulated environment. Less concentrated industries will be more likely to cause the duplication of research to take place. Hence an increase in the concentration in an industry can produce apparent savings via the reduction in the overall R&D effort, by reducing duplication, but at the potential (social) cost of reduced scope for different solutions to compete against each other. To the extent that existing economic analyses in their stress on savings due to economies of scale, fail to weight, or assign low weights to, the *benefits* of research duplication, they will over-emphasise the short-term savings to be made from increased cost efficiency in R&D at the expense of the long term gains to be had from greater technological diversity.

The point we want to stress is that much rests upon the conception of technological decision-making which underlies any model used to assess the costs and benefits of increased integration. On such a view, the perceived benefits of technological diversity will be low, because different technological solutions are, in theory, rankable according to their proximity to the best design and to the future ease of attaining this design. Factors which can contribute to technological diversity, such as different standards and regulations, are hindrances to this progress, primarily because they increase product prices.

Unfortunately much of this view of the world does not correspond very closely to the world which we inhabit. "Old" technologies are often not fully superseded, especially in niche conditions. Thermionic valves still have a role to play in electronics (for example in military technology) (5), water power never fully disappeared with the advent of steam power in the nineteenth century (remaining more efficient in areas where high heads were prevalent and coal transport costs high - ie. mountainous areas). The capture of kinetic energy from water flows has continued to improve, and turbine technologies subsequently "fed back" into steam power, producing significant efficiencies in electricity generation. In this sense technological progress can be taken to include the maintenance of both currently use-

(5) They are far less likely to be disabled by the electro-magnetic pulses produced by nuclear explosions and have been used by the Soviet Union in their more advanced fighter-bombers (the Pentagon's initial ridicule was played down when this was realised in the early 1980s).

ful ("old") niche technologies and potentially useful cross-fertilisations between different technologies, some of which may be of an older vintage. The latter are very important. The stronger the selection processes the less the scope for such cross fertilisation in the future. These are all things which the Whig view of technological history, which it would not be unfair to assert is particularly attractive to economists (technology as a trend variable) cannot easily take on board.

It is not unequivocally the case that different standards and regulations always reduce efficiency and hinder technological advance. Such factors can act as focusing devices which direct technological searching into directions which it would otherwise be far less likely to go. There can be positive unintended consequences to such searching. For example when the need to "invent around" a patent results in a major new discovery.

ASSESSING TECHNOLOGICAL DIVERSITY

There are two main dimensions to technological diversity which we must consider. Firstly, the potential economies which accrue over time from allowing different technological solutions to co-exist. Subsidiary policy questions relate to how long such co- existence should be allowed to continue for. Should it progress beyond the R&D stage ? If beyond that, for how long into the diffusion process ? Should lock-in effects (6) be counteracted as part of such a policy ? The second major area relates to the mechanisms which generate technological diversity : firm structures, user-producer relationships and national/regional cultures. These processes need to be better understood whenever specific choices about which candidates should be chosen are involved, given that it is rare for all potential developers to be allowed to operate, especially when the Commission's, and national government's R&D support are involved. If political horse-trading is to be avoided, or at least reduced, policy analysts will require a more solid analytical understanding of these diversity-generating mechanisms.

We suggest here that the process of technical change involves a sequential form of hypothesis-generation and hypothesis testing. A problem is identified : for example the need for more powerful and efficient braking systems on a train. The research process involves finding out more about the nature of the problem (eg. what limits the efficiency of the existing braking technology), and developing potential solutions to this problem. Commonly this involves decisions about whether to incrementally modify the existing operational technology (with the cost-reducing benefits of retro-fit technological change) or to develop wholly new solutions which involve scrapping the existing technology (7). In later stages different competing solutions are evaluated both in terms of technical superiority and in terms of the costs of both developing them within the R&D process, and manufacturing the new solution or retro-fit components. The process of conducting R&D is therefore extremely uncertain and complex. Those who emphasise (rightly in our view) the importance of the social context in the development of technologies are simply recognising that in such a complex and uncertain process decisions made about

(6) See Paul David (1985) and Brain Arthur (1985).

(7) See Hughes 1987 op cit for a discussion of this with references to other work.

technological solutions, both in terms of the perception of the problem, and the possible solutions to the problem and their selection, can be influenced by non-technological factors.

For example, the structure of information flows in a firm (between marketing, R&D and manufacturing functions) can have important effects upon both how problems, and possible solutions are ranked. If communication between marketing and R&D is poor then R&D personnel may be unaware of many problems encountered by users. If communication between R&D and manufacturing is poor then, again, rankings of solutions - which all have variable implications for production costs, are also changed. It is not hard to see that even simple assumptions about the quality of these information flows, by producing different rankings of design options, can produce different technological solutions. In this way informational structures can affect technological performance.

Let us consider technical artifacts as packages of technical trade-offs. For any particular vintage of a technology the trade-offs are fixed, and a particular design configuration has been chosen within the envelope of possible design configurations given the state of the art. Different design configurations can co-exist because they lie along, or within, the boundary defined by what is possible given existing technological knowledge (ie. they lie on or behind the technological frontier). (This sort of approach is familiar from "technometric" work which comprises part of the technological forecasting literature) (8). Much technical change is concerned with shifting the technological possibility frontier, for example by developing an aeroplane which can fly faster and further than was possible before, or by the pursuit of scale economies in power plant design.

We must recognise that technological trade-offs can be very complex and that the process of technical change involves placing particular values upon particular parameters : for example placing a higher value upon fuel economy than upon speed in transport system design. Indeed, the process in which changing factor prices change design priorities (ie. the weightings of design parameters) is well recognised in work on technical change. Because expectations enter into the picture, (developing a technology takes time and requires assumptions about future states of the world), and the capabilities of agents and their institutional conditions vary, it is not hard to see why these weightings are subjective and subject to variation.

One can therefore model, if so desired, the influence of different firm and national characteristics on technical change as different weightings of design parameters and different technical capabilities. The essential point to grasp is that because the trade-off structures are often complex, such that there is no purely technical "optimum" design configuration at any point in time, and because subjectivity enters the picture, technical choice must inevitably be a social choice within perceived technical constraints. Even if all agents share exactly the same weightings of design parameters, it is only in very simple technologies that the trade-off structure is sufficiently simple that a purely technical optimum design configuration exists. When one takes into account the fact that at any point in time there may be more than one trade-off to attempt to shift, and that path-dependency exists

(8) See the articles published in various issues of the journal Technological Forecasting and Social Change, and in particular Sahal (1985).

(ie. what one did in the past matters) then it is not hard to see that technically determined technological development must be a rather rare special case.

True, the compulsive sequences in the development of a technology so familiar to economic historians (the notions upon which more recent notions of technological trajectories and the like have been based) do imply fairly narrow constraints on the technological development process. However such compulsive sequences probably depend upon relatively unchanged weightings of design parameters, and in any case it is difficult to disentangle the technical from the economic and the social. Such compulsive sequences can be initiated along different trade-off prioritising patterns, and they need not necessarily converge.

We suggest that thinking about technologies in this way (which represents a sort of "social construction of technology" approach, which is perfectly compatable with choice-theoretic analysis (see Farmer and Matthews, 1991) might help us to determine whether observed technological diversity could have positive consequences for the economy or not. If we accept that different technological choices will tend to be made when, in effect, design trade-offs are weighted differently, then the fact that diverse technological trajectories can be identified with different national/corporate cultures can be no surprise.

Earlier we suggested that, traditionally, evidence of technological diversity has been viewed by economists either negatively, as indicating that some producers are simply operating behind the technological possibility frontier, or as otherwise economically uninteresting - "simply the product of cultural difference" and "a problem of more interest to sociologists than to economists". However it is perfectly apparent that alternative technological approaches to the same problem may be equally successful in the market place, to the extent that the user of one approach has little or no market incentive to move in the direction of competitors' technological approaches. The co-existence of different successful technological solutions is indeed partly why intra-industry trade exists. Bi-directional trade between nations in the same commodity classes must in part represent the extent to which design and mode of manufacture represent part of what the consumer is choosing. Alternative technological approaches to the manufacture of particular products are indeed often treated as exemplars of national cultural differences.

What we wish to emphasise is that technological diversity in the region of the technological possibility frontier, (the set of possible technological configurations which are feasible for relatively successful market competitors) is of economic interest. Policy which assumes that convergence towards some particular technological approach or configuration is possible and desirable, and is evidence of technological progress, is myopic. The fact that a number of different technological solutions are equally successful under a given set of market conditions is however no guarantee that all will continue to be successful if these conditions change. And even aspects of a supposedly moribund technology may be reinvigorated by changes in the economic and technological environment. Policy needs to recognise that any tendency to eliminate technological diversity represents diminution of the technological resource pool, even if, via such processes as gains from economies of scale, short-term efficiency is increased by convergence. Thus, there is likely to be a tension between the robustness to environmental change provided by diversity, and the efficiency gains which may be consequent on convergence to a short-term optimum technological solution, where such a unique optimum exists. Since firms whose technologies become outmoded by change in the economic environment can learn from their better adapted competitors, Lamarckian adaption is of course possible in this case.

Given the policy-relevant trade-off which may occur between technological robustness and short-term efficiency, what criteria can we use to attempt to identify potentially valuable technological diversity ? We suggest two linked criteria.

(i) Firstly, the value of observed technological diversity should be assessed in relation to potential and likely changes in relative factor prices or other factor conditions. The more likely changes in the factor price (or factor availability) environment are though to be, and the more divergent the sensitivities to such differences of the alternative existing technological solutions in a particular field, then the more valuable will be maintenance of technological diversity.

(ii) Secondly, there is the issue of how fast and cost- efficiently firms can move towards new (to them) target technological solutions, in response to changing economic conditions such as factor price changes. Can they learn significantly faster when technological solutions in their new target region already exist and they do not have to invent them for themselves de novo ?

With regard to the technical and institutional characteristics, it is possible to identify two layers of diversity. In technical terms, diversity can rest on both the balance of technologies selected, and the specific types of technology developed within each selection. In institutional terms, it is possible to identify the formal structures adopted (type of organisation, pattern of ownership etc) as well as the specific relationships which develop between different branches of the industry and/or between the industry and the governance structure. The diversity in performance is essentially a function of the interaction of technology and institutions at both levels.

A CRITICAL NOTE ON ECONOMIES OF SCALE

The identification of economies of scale (whether these are treated as being independent of technical change - as in the neo-classical production function - or dependent upon technical change for their achievement - as in the engineering influenced literature, (see Gold, 1981)) involves two principal dimensions : size and speed. Economies of scale associated with constructing larger units rest upon arithmetic volume-to-surface-area relationships. Economies of scale associated with larger rates of output on the other hand (often involving larger plants) relate to the production speed dimension. So called dynamic returns to scale often boil down to the assertion that faster production in possible thus reducing unit costs as output flows past fixed facilities at faster rates. The spreading of overheads effect which occurs with increases in the cumulative volume of output can be independent of production speed and involves "up-scaling" production through time. These are all factors which produce "minimum efficient scales of production, (which form a major plank in the Commission's assessment of the economic gains to be had from increased integration).

Where network technologies are concerned there is another dimension, which is in fact also important in the speed dimension to scale in manufacturing. These are the economies consequent on increases in *system frequency*. The rate of output in both networks and in non-continuous manufacturing is often increased by eliminating processing bottle-necks which increase the frequency of cycles in the system. In other words less time is spent by the system not producing. This could involve a doubling of the volume of goods carried on a railway line by doubling the frequency of train journeys, doubling the volume of telephone transmissions by doubling system clock speeds, or doubling the output of a factory by eliminating a processing bottleneck when there is spare processing capacity elsewhere in the production process. In other words whenever the time-profile of output exhibits square wave like behaviour there is scope for increasing output by reducing the duration of the "troughs". Only when such troughs are eliminated is it necessary to increase the speed of propagation of the actual units moved around the system.

This important dimension of the efficiency of operation of both network technologies and goods production which is not adequately captured by the concept of economies of scale (though it is often hidden within scale effects). Yet, it is important with respect to diversity. This is because any diversity which has a detrimental effect upon the operators' ability to increase the system frequency poses a serious problem. On the other hand, diversity which does not pose such a problem, or even helps to consistently increase system frequencies has a rather different status. Because organisations are essentially information processing systems, similar processes are important in relation to organisational scale. We would suggest that the "economies of frequency enhancement" (at present subsumed with aspects of economies of scale) be further explored in relation to many of the particular issues (such as telecommunication standards and flexibility in production technologies) which bear upon increased economic integration in the community (9). Only after we have dealt with the mechanisms which produce economies of scale in more detail will we be in a position to (more) effectively analyse the scale-driven benefits to increased integration.

CONCLUSION

In this paper we have attempted to counter-balance the arguments in favour of increased European industrial integration resting upon assumed benefits of economies of scale by putting the case for recognising the value of industrial diversity in both technological solutions to problems and the institutions which support technological advance. This is not of course an argument against improved integration per se.

We see both technologies and institutions as mutually interacting elements, each helping to form the other. Although in broad agreement with commentators such as Geroski that present CEC policy may over-estimate the importance of economies of scale vis-a-vis the benefits of diversity in products and processes, we have developed a slightly different line of argument. In particular we have suggested that analysis in this area should not shy away from examining the non-technological

(9) In Matthews (1991) discusses this frequency point in more detail.

influences upon technological dynamics in order to understand, and possible forecast the future behaviour of, diversity *generating* mechanisms.

This runs somewhat against the usual economic assumptions about where the domain of economic analysis ends and those of sociology, political science and engineering begin. As we hope we have made clear, policy towards technology must develop a more sophisticated analysis of both the limitations to assumptions about economies of scale, and the economic gains consequent on given levels of diversity. The "resource pool' dimension of diversity is in our view an important issue whenever there are significant perceived risks involved in focusing upon a particular class of technological solutions (usually by particular firms). As we have suggested, if there is a risk that the "environment" may change thus warranting different technological solutions, and there are costs and time lags involved in agents shifting technologically into the new area, then there are grounds for encouraging a certain amount of technological and institutional diversity. However, care must be taken that arguments is favour of diversity are not used opportunistically by those seeking (via political mechanisms) to protect particular firms and industries. This is precisely why we need to be as rigorous as possible in our assessment of the economic benefits of diversity in *particular* technological areas.

Evolutionary economics (which we would expect to be able to tell us something about the role and sources of technological diversity) has not addressed policy issues of this sort to date. If the policy implications of diversity-based arguments (which must surely be one of the major potential areas of policy impact for evolutionary economics) are to be developed then, we argue, the methodological recommendations made in this paper should be adopted. Otherwise it will remain an area of limited policy impact : the facade of science without the policy impact of a science.

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