Innovation, Sustainability, Development: A New

MANIFESTO

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development

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3Ds

STEPS centre

About the paper

Notions of 'progress' pervade the modern world. Yet, 'north' and 'south' alike, policymaking for progress in innovation, sustainability and development tends to be ambiguous. Politicians speak of "the way forward", without saying which way. History is viewed as a "race to advance technology", without stating the particular direction. Governments proclaim "pro-innovation" and "sustainable" policies, without specifying which options or values are prioritised. Dissent over choice of directions is treated as generally "anti-technology". Queries are restricted and polarised around: "yes or no?"; "how much?"; "how fast?"; "who leads?" More searching questions are neglected over "which way?"; "who says?"; "why?" This is a fundamental problem, because the reality of progress towards sustainability is very different. There are many possible pathways; each looks preferable under different values or interests. Particular paths to sustainability can 'lock-in' or 'crowd out' alternatives. In a globalising world, we cannot realise all feasible or viable pathways. Conventional distributional measures aim at reducing inequities in implementing paths privileging the powerful, rather than pathways enabling the poor. This paper argues for a more deliberate, equitable and accountable politics around progress towards sustainability. Only by nurturing diversities of pathways to sustainability can we confidently reduce vulnerability and empower the least advantaged.

About the author

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About the Manifesto project

In 1970 a radical document called The Sussex Manifesto helped shape modern thinking on science and technology for development. Forty years on, we live in a highly globalised, interconnected and yet privatised world. We have witnessed unprecedented advances in science and technology, the rise of Asia and ever-shifting patterns of inequality. What kind of science and technology for development Manifesto is needed for today's world? The STEPS Centre is creating a new manifesto with one of the authors of the original, Professor Geoff Oldham. Seeking to bring cutting-edge ideas and some Southern perspectives to current policy, the New Manifesto will recommend new ways of linking science and innovation to development for a more sustainable, equitable and resilient future.

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About the STEPS Centre

The STEPS Centre (Social, Technological and Environmental Pathways to Sustainability) is an interdisciplinary global research and policy engagement hub that unites development studies with science and technology studies. Based at the Institute of Development Studies and SPRU Science and Technology Policy Research at the University of Sussex, with partners in Africa, Asia and Latin America, we are funded by the Economic and Social Research Council.

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ASPECTS OF PROGRESS

What is the nature of human 'progress'? Few ideas in the modern world are as prominent, as widely held or as influential. Indeed, the notion of progress is a defining characteristic of modernity itself. Most recently, key progressive themes are reproduced in debates about 'Sustainable Development'. Yet the details are often ambiguous. They become more so, the more carefully they are considered. At the deepest level, our understandings seem to spring from two quite distinct but mutually-entwined roots.

On the one hand, there are ***normative*** visions for progress – evaluative frameworks under which we might judge whether change is for better or worse. These are defined according to different institutional, political or cultural commitments. Each vision variously encompasses interests, values and aspirations concerning how we may better understand the world; the manners in which we should act in (or on) Nature; and the ways in which we ought to relate to one another and structure society. It is a common feature of disparate notions of progress, that commitments in these contrasting areas are consistently seen as interlinked and co-determining. However conceived, progress in our ways of knowing is seen to foster progress in our ways of acting, which together help achieve progress in the ways we live. Appeals to these kinds of resonating normativities of progress help shape contemporary politics. Yet the detailed values in question in any given instance are frequently left unstated. In policy debates around the world, there are few more effective ways to advocate a contested normative position (or vested interest), than simply to ignore alternatives and assert it as 'the way forward'.

This leads, on the other hand, to an ***ontological*** aspect of progress – represented as an inexorable driving force in human affairs. This is not so much about the way we want things to be, as how we think they actually are. In this guise, progress is encountered – whether we like it or not – as a supposedly inescapable determinant in the evolution of our knowledges, technologies and societies. Obscured by uncertainties, the detailed configurations of progress are typically not resolvable in advance. As with normative values, the specific characteristics of these ontologies of progress also vary across perspectives. But the common denominator is, that knowledges, technologies and societies more widely are held as pre-disposed to unfold in particular ways rather than others. Our ideas of the scope for human agency and social choice are thus reduced to restricted manoeuvrings under an essentially fixed set of imperatives. Whether we thrive or languish is seen to depend on how well we anticipate, pursue or adjust to this single inevitable course of development. Hence the resigned fatalism even among sceptics and critics of particular developments around the world, that 'you can't stop progress'.

In each of these contrasting aspects, notions of progress are deeply implicated in, and by, the exercise of power. Nowhere is this more true than in political debates over the standing of different forms of knowledge, the prioritisation of alternative kinds of innovation or the pursuit of contrasting development strategies. In all these areas, particular contestable values and interests are routinely protected from scrutiny by concealing them behind invocations of an apparently unitary and objective 'way forward'. The effect is to assert the favoured vision at the expense of other possible values and directions for change. Once generally established as the supposedly uniquely possible path for progress, then a particular interest or normative position acquires the status of ontological inevitability. Herein lies the link between normative and ontological aspects of progress. The cloaking of evaluative ambiguities shades into the negation of substantive scope for choice, discussion and even thought.

Of course, the particular values and interests that are most frequently embedded in such unitary notions of progress are those associated with incumbent institutions and privileged social groups. It

is these social actors who (by definition) disproportionately shape discourses of progress. Patterns of power in society may thus be seen not only as outcomes, but also as determinants of our understandings of progress. As a result, our imaginations of progress are – ironically – a principal factor conditioning the ways our progress actually unfolds. Though ostensibly imminent in the conditions encountered in our future possible paths, the determinants of progress are really following in our footsteps. Indeed, often unrecognised in our familiar surroundings and consciousness, the drivers of our progress are quite literally 'breathing down our necks'. In contemplating the directions taken by our knowledges, technologies and societies, then, the challenge is therefore not so much to celebrate or criticise the details of what contingently emerges in the unfolding paths of knowledge, innovation or development. Open, inclusive, reflexive deliberation over alternative outcomes for progress is a crucial social faculty – and a necessary condition for any truly democratic polity. But contemplation of outcomes alone does not address the general underlying, recursively co-evolving links between disparate future potentialities and diverse current interests, imaginations, aspirations and expectations. The most vital and neglected responsibility is thus to engage directly with the underlying formative circularities themselves – the often invisible ways in which our normative commitments construct the actual directions of progress.

The central argument of this paper is quite simply stated. Whether we are focusing on knowledge, innovation or development – and wherever we look in the world – the same basic dynamic recurs amidst the contrasts. Multiple – often radically different – orientations for change are typically feasible and viable. Different directions are favoured under divergent values and interests. Yet mainstream debate over choices between these possible paths tends to revert to polarised discussion around some single, ostensibly unitary, vision for progress. This is as true of Sustainability discourses as it is of preceding and parallel visions of progress. Often, the position is expressed as if there were 'no alternatives'. The questions asked are thus typically restricted to 'yes or no?'; 'how much?'; 'how fast?' and 'who leads?' If we move instead to more plural understandings of progress, then the quality of debate – and of the ensuing choices – thereby stands to be enriched. Instead of fixating on some single contingently-privileged path, we might ask deeper, more balanced and searching questions about 'which way?'; 'what alternatives?', 'who says?' and 'why?' This is the essence of a normative, analytic, epistemic, ontological – and consequently intrinsically political – project of 'pluralising progress'.

As one of a number of background papers for a 'New Manifesto' on innovation, sustainability and development, this paper will draw out some of the implications of these themes. This is an initiative of the UK Economic and Social Research Council Centre at the University of Sussex on Social, Technological and Environmental Pathways to Sustainability (STEPS). Although the underlying issues are quite straightforward and highly practical in their everyday policy implications, some of the details are necessarily rather complex. Indeed, this is partly why they have remained so neglected in current mainstream academic and political debate. The issues are further obscured by the ways in which they are quite systematically occluded by the grain of conventional disciplinary thinking and policy language – concentrating as these do on the simple expediency of 'one way' narratives. In order to try to illuminate these crucial but hidden aspects, the discussion must therefore in places sometimes become quite technical. In order to try to help alleviate this, a short summary of the key argument is provided at the end. The paper will also use the straightforward device of focusing on three practical prescriptive implications for governance of innovation, sustainability and development: the '3D Agenda'. It is this agenda that provides a major element in the framework for the collectively-developed STEPS manifesto, with this paper consequently providing a key part of the analytical base. The three 'D's in question are those of the present title. ***Directionality*** refers to the need for more open academic and policy attention to the fact of there being alternative possible orientations for progress. ***Distribution*** refers to the imperatives for greater democratic agency, political accountability and social equity in shaping the drivers, benefits and vulnerabilities associated with alternative orientations. ***Diversity*** refers to the value of nurturing more plural discourses and

cultures around deliberate choice of portfolios of pathways for innovation, sustainable and development – allowing greater variety, dynamism and context-sensitivity in technological and institutional trajectories.

The paper will develop these themes in a series of cumulative steps, each drawing out different implications that flow from the interlinked normative and ontological aspects of progress in modern societies discussed above. In the next section, we will explore some of the key contrasts and underlying commonalities between discourses about progress and more recent policy debates over Sustainability. The following section will examine how these contending normative issues relate to common ontological assertions concerning the inherent necessity of progress. Based on this, the subsequent section will review a broad multidisciplinary literature concerning the multiplicity of ***directions*** in technological progress – indentifying the many ways in which social choice gets 'closed down' around a restricted subset of possibilities. Following this, discussion will turn to the implications that are raised for debates over the ***distributional*** challenges in social, institutional and technological development. The penultimate section of the paper will then argue for the importance of fostering greater ***diversity*** in the ways societies go about appraising – and pursuing – divergent trajectories in knowledge, innovation and development. In the concluding section, the key steps in the argument will be summarised and some wider reflections offered on the role of progress in the distinctive 'origin myths' of modern society.

PROGRESS AND SUSTAINABILITY

In normative terms, the issues entwined in contemporary ideas of progress are as old and deep as humanity. Progressive visions arise in many forms and eras, across a variety of cultures (Bury 1987). But the global stakes and rhetorics have intensified in the past couple of centuries. In this period, the passage of history has built a powerful worldwide hegemony around some highly specific and idiosyncratic ideologies of progress (Almond et al 1981). Conventionally traced to the European 'Enlightenment', many of the constitutive values are actually rooted far before (Nisbet 1994) and beyond (Needham 1959) this setting. Vocabularies remain varied and hotly contested (Wessels 2006). The actualities are even more so (Burgess 1994). But wherever we look in the world, we find mainstream notions of progress that are circumscribed in quite similar terms (Santayana 1998; Simon 1995). One key strand concerns ambitions to 'advance' our understanding of the world through contrasting conceptions of 'reason', 'rationality' and 'science' (Laudan 1977). Another centres on the aim of intervening in Nature through application of material, processual and organisational technologies – and so helping to ameliorate different kinds of human frailty and vulnerability and enhance human potential (Mokyr 1992). A third highlights variously understood versions of 'democracy', 'emancipation', 'empowerment' or 'accountability' as general imperatives in political life (Nelson 2006).

There can be no doubt about the many benefits that can arise from sincere and active pursuit of these broad evaluative frameworks for progress. But immediate questions are raised at the outset. How are we to interpret such general aspirations? Which styles of rationality are to be upheld as a template for progress, exercised by whom and under which precepts and constraints (Hollis and Lukes 1982)? Which knowledges and disciplines are to count as progress in 'science' and which not (and to which extents) (Jasanoff 2005)? What kinds of technological interventions represent the best reflections of progress? To what extent is progress about technological artefacts and to what extent does it implicate social relations, institutional structures and cultural perspectives? Either way, does progress tend to lie in interventions that aim to control Nature, or in more subtle and effective means to respond to complexity and irreducible vulnerability? And what exactly is meant by progress in democracy or social justice? With such varied and dynamic patterns of contending values and interests in modern plural societies, what is to count as the single most unequivocally 'progressive' path for social change? Which particular instruments, procedures and institutions offer the most

progressive ways to achieve greater empowerment or accountability? As with any such broad ambitions – and even for this single apparently quite specific mainstream 'Enlightenment' understanding of progress – the proverbial devil is in the detail.

Of course, none of this is to say that 'anything goes' in what counts as progress. Evaluative frameworks are not entirely open-ended. For instance, across diverse knowledges, there is a widely-held intrinsic value to advancing our understandings of the world. Whether or not recognised as 'scientific', most agree that improvements in knowledges and social learning can help significantly to enhance human wellbeing. Many have experienced how exercise of ever more subtle forms of intervention (through both social practices and material technology) can protect, expand and enrich particular areas of life. It is clear that diverse forms of democracy and empowerment can massively amplify these benefits – and render them more equally distributed. Examples of the potential for these ambitions abound in areas like food, health, shelter, energy, environment, education, welfare, materials, mobility and communication. In all these areas and others, the life experience of many in the world now would be unrecognisable only a few generations ago. In a world in which one and a half billion people are living 'without sufficient means for human survival' (Chen and Ravallion 2008; Parsons 2008), where the privileged few dominate a disadvantaged majority and at a time when gaps between rich and poor continue to widen, there can be no doubt about the moral and political imperatives to further realise the potential of these broad normativities of 'progress'.

Yet nonetheless, there exists much debate over the deeper, more general and more nuanced normative implications of current notions of progress. In what senses, under which perspectives and in what contexts should we view particular emerging pathways or outcomes as good or bad? To what extent can professed commitments to these kinds of progress actually be taken at face value? Whether through misfortune, myopia or mendacity, declarations of ostensibly progressive aims have all-too-often remained tragically unfulfilled. 'Advance' in particular kinds of knowledge has often occurred at the expense of reversals – or deliberate suppression – of others. Apparently enlightened advocacy of 'rationality' and 'reason' has frequently reduced to unreflective imposition of doctrine. What counts as authoritative knowledge is often as much a reflection of institutional power as it is of robust or comprehensive understanding. Interventions aimed at control on the part of some may inherently prompt alienation or vulnerability on the part of others. And experience also shows how attempts to exercise social or technological control at one level can yield a host of unpredicted and uncontrollable threats at another. Perhaps most pressingly on this last issue, the result is a series of potentially existential global catastrophes, including: climate change, world famine, resource depletion, biodiversity loss, environmental pollution, novel pandemics and mass-destructive weapons. And even advocacy of 'democracy' itself is notoriously open to instrumental manipulation and dissonant outcomes (Chomsky 1996). In practice, history shows how prominence of this rhetoric is often accompanied by the compounding of various kinds of inequality, exploitation and even repression (Klein 2008). Despite apparently self-evident positive connotations, then, there can be no automatic, unqualified or unquestionable license for currently mainstream normative notions of progress.

Of course, the particular values discussed thus far represent only one possible family of values associated with currently hegemonic 'Enlightenment' notions of progress. Around the world, there exist many other divergent ways to characterise nominally progressive ideologies. In many particular areas of political discourse, these are each variously taken as constitutive of a range of more explicit and specific ideologies of progress. These come in diverse political flavours. For instance, broadly 'conservative' understandings of progress variously emphasise values characterised as individual autonomy, 'free markets', competitive behaviours, a reduction of the state, incentives rewarding 'success' and the 'trickle down' of wealth (Goklany 2007). Depending strongly on the context, diverse 'social democratic' perspectives on progress highlight issues such as equality of opportunity and equity of outcome (whether defined in terms of race, culture, gender, caste, class or sexuality), as well as social justice, reduction of poverty and vulnerability, welfare provision, cooperative

institutions and nonviolence in global affairs (Jameson 1999). Many permutations play out on these themes, including additional values associated with various forms of national or cultural self-expression, religious freedom or particular doctrinal commitments. In recent decades, diversely construed environmental values form an increasingly important further array of ways for evaluating progress (Christoff 1995). The essential point is that each of these interpenetrating value systems may be taken to define radically divergent orientations for social, economic or technological progress. Against this rich kaleidoscope of commitments, the persistence of an apparently single unitary mainstream normative understanding of progress looks increasingly untenable (Herrigel 2000).

Over the past quarter century, global governance discourses have seen the emergence of a new and significantly more explicit and transparent arena within which to engage with these contending normativities in the defining of progress. This centres on the advent of 'Sustainability' and 'Sustainable Development' as leitmotifs for ostensibly globally-shared values in production of knowledge, fostering of innovation and pursuit of development (UN 1992). Of course, it is a notorious feature of most mainstream policy discussions in these areas that 'Sustainability' can also remain tantalysingly ambigous with respect to exactly what is implied (Dobson 1996). As with other normativities of progress, the devil is in the detail. Indeed it is this quality of interpretive flexibility that forms a key part of the reason for the prominence of the language of Sustainability (Bijker 1995). And there is much active contestation between alternative formulations of 'Sustainability' and 'Sustainable Development' – and between contending understandings of each (Meadowcroft et al 1996). Nonetheless, the seminal formulation of the 1987 international Brundtland Commission introduced a degree of explicit normative focus that is unprecedented and without parallel in wider and older 'Enlightenment' understandings of progress (Murcott 1997). The canonical encapsulation of this position, is the injunction that policy should aim at *'meeting the needs of the present, without compromising the ability of future generations to meet their own needs'* (WCED 1987).

Although the progressive novelty of this principle is often characterised as resting on the attention to 'future generations', the emphatic requirement that the needs of the present also be met was (and is), if anything, even more immediately radical. In subsequent elaborations on this theme, the essential thrust of Sustainability concepts in formal international governance debates consistently rests on three broad sets of broad normative values – each addressing different forms and contexts for human needs (UN 1992). The first concerns human wellbeing – including health, education and community coherence as well as economic development (MDD 2000). The second relates to social equity – across diverse groupings of people among both present and future generations (UN 2002). The third refers to environmental integrity – in terms of various forms of ambient pollution, ecological integrity and resource availability (UNEP 1997). It is in these ways that 'Sustainability' has, for the last two decades, been the principal global policy discourse enjoining the reversal of persistent maldistributions of privilege, appropriation and vulnerability affecting a large proportion of the world's population.

Having said this, it has to be acknowledged that the term sustainability is also often used in mainstream policy debates in much more instrumental ways. These threaten seriously to obscure and undermine this new and potentially significant form of normative specificity. Here there is a particular expediency, in that the broad colloquial meaning of the term 'sustainability' (in English as in other languages), refers generally to the maintaining over indefinite periods of any unspecified features, qualities or functions (OED 1989). This provides a linguistic license for legitimatory usages of this vocabulary – even in discourses concerned with the central human and environment problems of Sustainability – in ways that are inattentive, ignorant or actually potentially undermining of these same values. For clarity, this paper therefore refers to general colloquial meanings with a lower case 's' and the more specific policy-related 'Brundtland' meanings with a capital 'S' (Stirling 2009a). This is like the conventional orthographic convention distinguishing general use of the adjective 'conservative' from the still broad but more specific category 'Conservative'. For instance, in

the Treaty Establishing the Constitution for Europe (CEC 2004), we read of the need to sustain the internal market (Art. III-130.4), member state economies (Art. III-179.3), and government financial positions (Art. III-198.1b) – as well as the distinctive qualities of Sustainability (human wellbeing, social equity and environmental integrity) mentioned much later (Art. III-292d). In the commercial world, we hear routinely of 'sustainable business' in a fashion that emphasises not the human, social and environmental values of Sustainability, but factors that may be strongly in tension with these, like 'profitability, competitiveness and market share' (SBI 2005). In UK government discussions, the term 'sustainable communities' is likewise deployed in a fashion that reduces the entire environmental agenda to just one of nine mainstream policy aims – on a par with 'good transport services' (DCLG 2005).

Given its environmental remit, the UK environment ministry, DEFRA, provides a particularly revealing example of the potentially perverse outcomes that can arise from these nonspecific and instrumental usages of the terminology of sustainability. Despite undoubted commitment and effort in pursuit of Sustainability in the Brundtland sense, the high-level organizational structure of this department has nonetheless long made prominent reference to sustainability in a fashion that contradicts its own detailed indicators (DEFRA 2004). All agricultural activities, for instance, have been routinely referred to in undifferentiated ways as 'sustainable farming' – implicitly neglecting to recognise any form of farming extant in the UK as being in any way 'unSustainable' (Stirling 2005). Likewise, DEFRA agencies employ the term 'sustainable science' to include areas of research concerned with the use of pesticides in agriculture (DEFRA 2002), despite the fact that reducing pesticide use features strongly among DEFRA's own formal Sustainability indicators (DEFRA 2004). In effect, in these kinds of discourses, DEFRA (like many other institutions) is representing as sustainable, practices that they elsewhere acknowledge to be unSustainable.

These kinds of dynamics in political discourse reproduce for the term sustainability many of the features already discussed in relation to the language of progress. Nor is this phenomenon new, or restricted to these debates alone (Gramsci 2000). This general form of rhetoric is a widespread and well documented means to 'manufacture consent' (Chomsky 2002). Multidimensional meanings are reduced. Normativities are concealed. Ambiguities are harnessed to expedient ends. Selected subjectivities are invested with ostensibly unitary objective status. Already-privileged values and interests are further reinforced. Yet despite these familiar pathologies, the elevation of sustainability discourses to the highest levels of contemporary politics nonetheless represents a significant development. Arguably for the first time since the Enlightenment, mainstream normatively-sanitised notions of progress are subject to calibration under a comparably hegemonic framework. As a result, policy debates are engaging (at least discursively) with progress not simply as the contingent emergent outcome of the evolution of incumbent institutions and markets. Instead, Sustainability discourses, despite their imperfections, are helping to illuminate the essential plural, rather than unitary, nature of progress. In place of a single inevitable trajectory, we begin to perceive a multiplicity of potential pathways – and thus a role for explicit evaluation, active politics and deliberate social choice (Leach et al, forthcoming).

PROGRESS AND NECESSITY

Despite the emergence around Sustainability of more explicitly normative policy discourses within which to evaluate progress in knowledge, innovation and development, mainstream representations of progress continue to remain restricted, opaque, ambiguous and deterministic. Across the world, elite political figures repeatedly couch progress in essentially technological terms. National leaders routinely defer in justifying decision making to the supposedly determining role of 'sound science' (Blair 2003; Busquin 2003) or 'advanced technology' (ATP 2007) – without specifying criteria of 'soundness' or 'advance'. There is similarly high-level support for the asserted self-evident benefits of undifferentiated 'pro-innovation' policies (Brown 2004; European Parliament 2006) – without

discussing which specific innovations are being referred to. Quite specific public misgivings over particular technologies are stigmatised as indiscriminate 'anti-science' (EU EGST 2004) or 'anti-technology' anxieties (UK Council on Science and Technology 2000). In areas like GM crops or nuclear power, leading scientific figures repeatedly assert quite explicitly that there is 'no alternative' (King 2006).

Although many of these leading figures are somewhat coy about elaborating on the thinking behind these statements, others are more helpfully forthcoming. The uni-directional technological determinism underlying so much of this elite thinking on progress was particularly well expressed in recent years by the President of the British Royal Academy of Engineering, in the globally-broadcast and widely-cited BBC Reith Lectures. Here, history is portrayed as a one-track 'race to advance technology' with the challenge of government being simply 'to strive to stay in the race'. Looking forward, we are told quite explicitly that it is technology that 'will determine the future of the human race' – rather than the other way around. This is a strikingly literal notion of the human race! In it, incumbent patterns of technology change are seen as self-evidently good, with the role of 'the public' being simply to 'recognise ... and give [technology] the profile and status it deserves' (Broers 2005). It is interesting how often the purported Enlightenment values of objectivity and reason can, in attempts to defend this kind of vision, so often become overtly emotive and partisan. Senior politicians routinely treat dissent over particular favoured directions for technological change not as legitimate evaluative positions, but in animated language as 'prejudice' (Wicks 2005) and 'unreason' (Taverne 2005). Indeed, to a recent UN Deputy Director-General, criticisms of incumbent technologies like GM foods are attributable to indiscriminately 'anti-technology protestors', described rather breathlessly as 'members of the "flat earth society", opposed to modern economics, modern technology, modern science, modern life itself' (Malloch-Brown 2001).

These kinds of mainstream elite representations of progress and its supposed enemies can be recognised the world over. Again and again, they display all the strategic expediencies with which this paper began. They obscure – or explicitly reject – the legitimacy of evaluative positions that discriminate between different applications of knowledge, priorities for innovation or directions for development. Beyond this, the effect is implicitly to deny even the relevance of normativity in considering matters of progress. In any given area of socio-technological change, particular sets of incumbent values and interests are dressed up in the ostensibly irrefutable ontology of one-directional progress. Science, technology and development are seen in any given context to be 'hard-wired' for a single possible pathway for change (Sarewitz 1996). This unitary 'way forward' is presented as self-evident and pre-ordained (EU 2006). Where choices appear dimly at the edges of the favoured course, the response is that 'there is no alternative' (King 2006). Where there are doubts over the committed direction for advance, the resounding chorus is, that 'you can't stop progress' (Gray 1999). All we have left, is an intrinsically tautologous and self-referential circularity, in which whatever happens to emerge from established structures of power and privilege in science, technology and development – will simply be asserted by these same interests as constituting 'progress' (Noble 1993). It is in this way that dominant discourses in knowledge production, innovation priorities and social change effectively take a Panglossian form, in which all that actually occurs is for the best 'in the best of all possible worlds' (Voltaire 1759).

To be fair, expedient elite discourses are not the only influence conditioning this monolithic hegemonic understanding of progress. Around the world there is much in wider everyday experience that seems to encourage similarly linear, deterministic views. If not strictly singular, the dimensionalities of global social and technological developments do appear severely constrained. Despite the many differences of experience between regions, classes, cultures, economies, ideologies and geopolitical settings, similar attributes repeatedly come to the fore in committed patterns of global change. Selected examples illustrate the general picture. In most countries, populations continue to grow. People are moving from the country to the city. Farms are becoming larger, employing fewer people and growing more dependent on external inputs. Diets are becoming

progressively more dependent on animal products and processed food. Craft skills are increasingly substituted by automated mass production. Transportation systems based on the private automobile are rapidly eclipsing other modes and systems. Energy use is rising inexorably. Electricity systems, in particular, are expanding as fast as infrastructures can be built.

And many consequences of these developments also show more specific resonances. Mobile phone use is increasing radically worldwide, transforming social and economic relations in unexpected ways as this occurs. Information technology is penetrating ever more areas of life, fostering further systematic changes in the ways organisational challenges are analysed, managed and communicated. Exponential growth of the world-wide-web is associated with pervasive structural changes in politics, media and the arts. Despite reversals, national economies increasingly emphasise liberalisation, deregulation, privatisation and reliance on commercial enterprise for public services. Global finance, businesses and supply chains are increasingly interconnected and co-ordinated. In knowledge production, there is an ever-increasing proliferation of technical specialisms – with correspondingly greater reliance on institutionalised forms of expertise in every area of life. A series of industrially-driven environmental problems are increasingly familiar worldwide – from climate change, through urban smogs and chemical pollution to water scarcity, waste management, soil depletion and deforestation. Novel pathogens seem to emerge with increasing frequency. In individual countries across the globe there are ever-increasing gaps between the income and life experience of the rich and poor.

Everywhere then, and in all these dimensions, the grain of contemporary developments seems often to run in broadly similar directions. The overall story is one of growth, concentration and acceleration, with parallel themes of erosion, alienation and inequality (ETC 2003). There are, of course, significant periods of interruption in these trends and important instances of turbulence. But these may be recognised as specific exceptions that underscore the general rule. Powerful eddy currents will always drag against a dominant flow. The point is that as time goes by around the world large scale changes in the ways we live, eat, see, hear, move, work, think and dream all seem increasingly to tell the same kinds of story.

How might we come to understand this? Impressive bodies of integrative historical analysis point at consistent patterns underlying long-run co-evolution of cultures, institutions and technology in the period since the advent of global colonisation and the first industrial revolution (Freeman and Louca 2002). Despite the enormous contextual contrasts, certain general features can be resolved. One tradition of analysis bearing directly on this issue of interlinked patterns in long term global social and technology change, for instance, discerns large-scale secular cycles, each of around half a century or a little more in duration (Schumpeter 1939; Kuznets 1940; Kondratief 1979). In this view, successive waves of intensely interacting social and technological innovations create new 'techno-economic paradigms' (Perez 1983) or 'socio-technical landscapes' (Elzen et al 2005). Eventually pervading the entire world economy, each is conceived as a process of 'creative destruction' (Schumpeter 1934; Abernathy and Clark 1985), involving episodes of explosive growth and structural change followed by a period of re-adjustment and dissemination. In its formative stages, each new phase of development is influenced, among other things, by incumbent interests and power dynamics acting in the preceding phase (Freeman and Perez 2000). In such ways, each wave is then held in turn to exert conditioning pressures on the orientations of consequent change.

One especially forensic and well-articulated analysis of this kind is quite explicitly global in its scope. An essential motor driving these dynamics is found in the complementary but contending characteristics of financial and production capital (Perez 2003). Each successive cycle in techno-economic progress is thus seen to involve the complex interplay of synergies and tensions between the two. In the industrial revolution that began in the UK in the late eighteenth century, for instance, a surge in availability of finance capital helped build pioneering infrastructures around machines, factories and canals. As this configuration of mutually-reinforcing production patterns was

disseminated and consolidated around the world, a new wave became evident. Initially often resisted by the entrenched structural interests arising in the first wave, this again began in the UK in the early nineteenth century. At this time, pressures of financial capital drove interlinked investments in steam, coal, iron and railways. As these forms of production capital then spread in their turn, the genesis of successive waves spread to the USA and Germany in the late nineteenth century, with the emergence of steel and heavy (electrical, chemical and civil) engineering. At the end of the nineteenth century, developments were driven principally from the USA: fuelled by the rise of the automobile and associated industries around oil, petrochemicals and mass production. Then, in the final third of the twentieth century, there emerged (again initially in the USA) a fifth wave around information technology and telecommunications. Looking forward, protagonists of this position foresee an imminent new global cycle of change, this time more geographically extensive in its inception and probably revolving around biotechnology, bioelectronics and nanotechnology (Linstone 2002) – possibly conditioned by Sustainability imperatives (Green et al 2002). Analysts associate these successive waves of formative creativity and destruction with pervasive shifts not only in industrial and economic infrastructures, but also in the character of wider knowledge production, institutional organisation and even cultural expression. So it seems there emerges in at least one well-considered and substantiated view an apparently quite unitary nature to the staging of large-scale long-run human progress.

Of course, these kinds of synoptic generalisations give rise to as many questions as they answer. Criticisms are raised over crucial details. Queries are posed over comparabilities across contexts. Scepticism is expressed over apparently determinist implications. The point is, however, that it is these kinds of long-term historical analyses of social and technological change that offer the most obvious reference point in seeking to understand the apparent uniformities in the worldwide unfolding of progress. Given the apparent endorsement for notions of a discrete and unitary orientation to progress, it is therefore worth considering some of the implications of this analysis in a little more detail. Any insights arising from this sophisticated body of enquiry are likely to be highly relevant to the more rudimentary rhetorics of 'no alternatives' and 'ways forward'.

The first point is that it is not correct to interpret this idea of long-term emergent globally-extensive 'waves' of change as necessarily constituting a more general ontology of one-directional technologically-determined human progress. Many of the principal authorities in this field are explicit and unequivocal about 'the wide space of the possible' in the substantive unfolding of any given phase – extending even to radically contrasting political-economies as well as divergent technological configurations (Perez 2004:236). This point is reinforced by considering biological evolution. The documenting of an iterative process in which periods of structurally stable equilibrium are punctuated by episodes of radical change is held in common between biological and techno-economic evolution (Loch and Huberman 1999). In the story of life on Earth, for instance, the recognition of this kind of 'punctuated equilibrium' in evolutionary dynamics in no way implies the determination of specific directions of change (Gould 2007). This is simply a feature of the process rather than the direction of change. Another contrasting trajectory of development under different contexts might also display similar patterns of creative destruction and consolidation – and even apparently similar regular periodicities – and yet unfold substantively in quite different ways (Gould 1997).

Likewise, repeated general structural associations and consistent patterns of causation need in no way imply that the substance of social or technological development is somehow pre-ordained. Financial capital and production capital (for instance) may interact in quite determinate ways, but the substantive consequences for the configuration of technologies may still remain at least partly contingent (Perez 2003). And suggestions that globalising processes of industrialisation seem to have unfolded in a broadly coherent fashion across the world, do not necessarily imply that this particular course of events was the only one possible. Prior to global integration through networks of colonisation and transoceanic trade, the shape of evolving human civilisations followed markedly

distinct patterns in different regions (Clark 1977; Chazan 2007). At a more detailed level in the next section there follows a review of the scope for counterfactual interpretations, in which many important features of more recent socio-technical trajectories can quite readily be seen to be subject to a multiplicity of contingent paths (Bunzl 2004). With essentially global processes such as colonialism or industrialisation – just like global climate or ocean ecosystems – the unfolding of a particular contingent path in no way of itself necessarily demonstrates that this particular path was inevitable (Hawthorn 1991; Ferguson 1998). In order to determine the relative importance of contingency and determinism in interconnected global systems like those around contemporary patterns of progress in human knowledges, innovation and development we need many such systems to consider (Morgan and Winship 2007). At the moment, the size of our sample of worlds is just one.

Of course, just as in Nature, there exist certain asymmetries in the evolution of knowledge, technology and society (Gould 1988a). The sequencing of configurations is not always contingent, but may often be necessary (Sahal 1985; Carroll 2001). It would be difficult, for instance, for a frontal cortex to develop in the absence of a central nervous system. The emergence of opposable digits presupposes the evolution of limbs (Gould 1980). Just so, it is impossible realistically to envisage creation of titanium alloys before the smelting of more readily melted copper. Likewise, it would be difficult to build electronic computers before the advent of electric circuits (Dosi 1982).

Development of many pharmaceutically-purified products like aspirin have only been possible through accumulated learning by sophisticated vernacular medicine based on in-depth experience of the properties of indigenous plants (Rist and Dahdouh-Guebas 2006). Yet even where they exist such necessities in the sequencing of particular configurations hold no necessary connotations of one-directional development. In technical terms they imply time asymmetry, but not single-path (or 'unicursal') progress. In more familiar terms the structures of wasp, fly and bee all follow from common antecedents. Yet these shared past stages of change did not determine the future pathways. And the realised forms of wasp, fly and bee represent just a tiny subset of the diverse possible configurations that might – under different contexts – have constituted feasible and viable branching evolutionary paths (Gould 1988b). So too, then, might contrasting assemblages of knowledges, technologies and institutions share common origins, yet display the potential for further evolution in quite radically different directions – each one of which constituting a feasible, viable and legitimate orientation for progress.

In conclusion to this discussion of progress and necessity, the basic message is clear. Persistent mainstream representations of human progress as technologically-determined, one-directional and essentially inevitable can find no necessary support in serious long-run historical analysis. The picture instead is much more nuanced. There are possible patterns in the dynamics of change. Not all developmental paths are equally likely. Some seem plain impossible. There are asymmetries in which kinds of configuration can precede others in time. But regularities that do emerge fall very far short of demonstrating a single possible pathway. There is nothing in this wide literature to refute that human processes of progress are as plural, rich and diverse as those displayed more widely by life itself. Somehow then, a multiplicity of potential pathways is reduced in order to arrive at the much more seriously restricted subset of trajectories that are actually realised. As we have seen, it may be that 'no alternatives' political rhetorics play a role here. But it would be unwise to jump to the conclusion that such substantive and extensive consequences are purely a result of discursive style. If not discourse alone, then, what other mechanisms are in play? There exists an overwhelming body of evidence for the drivers of constrained directionality in the unfolding of knowledge, innovation and development. It is to this subject that attention will now turn.

DIRECTIONS IN PROGRESS

Given the emphasis on 'sound science' and 'evidence based' positions in so much policy making on science and technology, it is interesting to consider how consistent with these principles is the central feature of mainstream discourse in this area. How well-substantiated is the 'unicursal model' (the 'one track', 'no alternatives', 'way forward', 'race to the future' concept of progress)? Discussion in the previous section showed how the manifest regularities in contemporary and historic social choices of technology are as consistent with a role for contingency and the conditioning effects of power as they are with any presumed ontological necessities. Yet, if the underlying potentialities of progress are truly plural, how exactly is it that they can be so readily reduced to such apparently unitary choices?

As in any area of academic life, there exists a plethora of different disciplines and sub-disciplines concerned with this issue – generating an even greater multiplicity of voices. Boundaries are jealously guarded and vocabularies zealously policed. In comparing perspectives from history, philosophy, sociology and politics, as well as all the various tribes of economists (for instance, neoclassical, evolutionary, institutional and ecological), there seems at first sight a bewildering diversity of interpretations and commitments. Yet when it comes to the basic answer to the question posed here, a remarkable degree of consensus develops. All these disciplines in different ways have arrived at understandings that technologies may – like biological species – evolve in a variety of alternative directions (Ziman 2000). Not all directions are intrinsically feasible or contextually viable (Freeman and Soete 1997; Perez 2003). Yet at any given point (for any specific artefact, as for entire infrastructures), there are typically a number of contrasting trajectories along which developments may progress (Dosi and Labini 2007). At each stage, various social, institutional, cultural and political mechanisms act to build highly selective social commitments that realise the actuality of only a restricted subset of these diverging potentialities (Williams and Edge 1996). As evolution unfolds, then, so pathways emerging earlier are 'closed down', but other possibilities are 'opened up' (Stirling 2008a). In this way, whether deliberately, blindly or unconsciously, societies 'choose' certain possible orientations for technological change rather than others (Collingridge 1983).

Depending on the context, there exist many specific processes through which societies can be seen selectively to commit to certain technological pathways rather than others (Geels 2002). Complex historic *contingencies* play a crucial role (Mokyr 1992; Fleck 1993). In other words, part of the story is random chance. And the intrinsic material *obduracy* of technology is also always a factor (Hommels 2005). But many systematic social mechanisms through which developments are 'channelled' in restricted subsets of the possible directions are also well documented (Kemp et al 1998; Elzen et al 2005). For instance, where technological performance depends partly on patterns of adoption, then powerful *positive feedback* processes are created in conventional market dynamics. Though they may originate in essentially random patterns, these simple dynamics of market '*lock in*' may become heavily directing of the course of change (Arthur 1989). The ubiquitous dysfunctionality of the QWERTY keyboard (David 1985) is an iconic example of the path-dependent consolidation of an initial purported accident of fate (Liebowitz and Margolis 1995). Despite successive technological revolutions, the cumbersome exigencies of nineteenth century mechanical typewriter design persist in current – supposedly highly competitive – consumer product markets (David 2001).

Similar mechanisms of *path-dependency* and lock-in may also serve to reinforce less arbitrary or politically innocent incipient patterns. The proximate social forces *shaping* early configurations of artefacts like bicycles (Bijker 1995), automobiles (Arthur 1994), road systems (Geels 2007), prisons (Foucault 1975), nuclear power (Cowan 1991), computer software (Church and Gandal 1992), chemicals production (Stringer and Johnson 2008), civil engineering (Winner 1977) and weapons systems (Kaldor 1981) can all be recognised typically to reflect the 'needs', preferences, normativities and interests of rather restricted social groups (Pool 1999). This is also true of the routines and practices (Nelson and Winter 1982) and paradigmatic ways of thinking (Dosi 1982;

Nelson 2008) extant in the most influential of successfully innovating organisations (Utterback 1993). These also become imprinted in the resulting technologies and their subsequently institutionalised trajectories (von Tunzelmann et al 2008).

More distributed pressures like those exerted by cultural *expectations* may also assert the sensibilities of relatively privileged social actors, such as entrepreneurs, investors, regulators and 'opinion formers' (Brown and Michael 2003). Once established in these ways, socio-technical configurations can become techno-institutional '*regimes*' (Rip and Kemp 1998), acquiring their own '*momentum*', at the expense of alternative (less privileged) configurations (Hughes 1983). These incumbent interests may then in turn come to exercise a degree of '*autonomy*' (Winner 1977) in their capacity to condition their own '*selection environments*' (Nelson 1993; Lundvall 1992), involving various kinds of '*capture*' (Sabatier 1975) and '*entrapment*' (Walker 2000) of ostensibly neutral, or even supposedly contending, social actors – like clients, regulators or legislators. Such is often observed to be the case in areas like nuclear infrastructures (Walker 1999), fossil fuels (Unruh 2000), automobile motoring (Geels 2007), industrial chemicals (Ashford 1994), genetic modification (van den Bergh and Holley 2002), cigarette manufacture (Kessler 2001), food additives (Millstone 1986), pharmaceuticals (Abraham 1995) and military systems (Kaldor 2007).

The overall picture is overwhelmingly one of powerful socio-economic and institutional-political pressures constraining a much more open plurality of scientific and technological possibilities. The outcomes yielded in realised technological trajectories represent only a subset of the configurations that might have proven feasible or viable under other contingent social, cultural or political circumstances. Although the specifics in any given instance suffer from the serious methodological challenges of demonstrating the counterfactual (Lewis 2001), it is not necessary to validate conclusively some specific relationship between divergent conditions and alternative configurations, in order to substantiate the general principle that technological progress is better seen as a generally plural rather than unitary phenomenon. However, given the earlier discussion of the newly established normativities of progress arising in Sustainability debates, there arises one further question. What if the plural scope of possibility were further constrained by applying further shared normative selection criteria? To the extent that the broad shape of commitments concerning human wellbeing, social equity and environmental integrity are increasingly widely accepted, perhaps this emerging (ostensible) political common ground does impose a rather more restrictive influence on possible technological pathways than might otherwise be suggested?

Perhaps the best way to respond to this query is to contemplate the particular challenge of global climate change. The imperative to reduce carbon emissions from energy use is one of the most specific, demanding and strongly consensual elements of wider Sustainability discourse (IPCC 2007). Emerging climate change mitigation policies are unique and unprecedented in the scale of current deliberate societal aims to influence the large-scale long-run nature of technological change (CEC 2008). The formidable character of this test is accentuated by the fact that existing discussions of technology change in this field are especially prone to a 'no alternatives' rhetoric (King 2006). Scepticism over mismatches between existing government and established market trajectories amplifies the sense of scepticism over the scope for choice (Adam 2008). As a result, policy making for 'transitions' to a low carbon economy tends even more than in other areas to be treated simply as a matter of 'management', with associated choices and normativities implicitly self-evident and thus devoid of political content (Smith et al 2005). If it can be shown that even under the intrusive and demanding requirements of climate change mitigation there still exists a recognisable plurality of choices, then the thesis advanced in this section of the paper will be further reinforced.

It implies no trivialisation of the monumental scale and urgency of the imperatives of climate change, to recognise that – in this area as in others – societies nonetheless still face real technological choices (Stirling 2008c). Even in the highly circumscribed area of electricity system strategies, there exists a multiplicity of technically feasible, potentially economically viable options,

each one of which might form the centrepiece for a system-wide transition. Major kinds of trajectory here include carbon capture and storage (IPCC 2005), a multitude of frameworks for demand efficiency and energy service innovations (Patterson 2009), alternative varieties of nuclear power (Craven and Rhodes 2003), centralised continent-scale renewable energy infrastructures (Scheer 2004) or shifts towards a diversity of new distributed small-scale Sustainable energy resources (Wood 2007) – permutations of each of which involve further infrastructure shifts to a 'hydrogen economy' (Holland and Provenzano 2007). A comprehensive and authoritative international comparative technology assessment literature is very clear that there exists a plurality of possible 'low carbon' pathways (World Energy Assessment 2000). Each path displays contrasting pros and cons, but all hold enormous potential for scale economies and learning-by-doing (Jacobsson and Johnson 2000).

Interestingly, on the rare occasions when confronted with the manifest contradiction of the 'no alternatives' vision, protagonists of this rhetoric respond simply by asserting instead that 'we should do everything' (King 2007) – a similar defence of the status quo, but one more step removed. Of course any real world strategy must inevitably involve some diversity. The point is not that only one pathway will be pursued entirely to the exclusion of others, but that not all of these pathways can be fully realised together (Stirling 2009b). Despite the strong normative imperatives and formidable technical constraints, climate change policy remains a further arena within which the prospects for future progressive technology change is emphatically open and plural, rather than closed and one-directional.

The overwhelming picture then, is one of societies acting – variously deliberately, blindly and unconsciously – to 'choose' certain possible orientations for technological change rather than others. Given this, it is interesting that the multiple disciplines responsible in various ways for these insights have had so little success in countering the restricted, opaque, ambiguous and deterministic representations of technological progress in mainstream politics. Despite the evidence, established elite visions persist of a unitary 'way forward', yielding a 'race to the future' with 'no alternatives' (Leach and Scoones 2006). This is not simply due to the entrenched political expediencies discussed at the beginning of this paper. Even some of the most well-informed disciplines have themselves been curiously circumscribed in the clarity and volume with which they address the reduction of directionality in technology choice. Various branches of economics, for instance, are responsible for some of the most profound, elegant and far-reaching insights concerning technological directionality. Yet, when the economics of technology engages with policy making – and especially politics more widely – the picture seems to become somewhat attenuated.

This point is best illustrated at a general level by considering the relative profiles of different areas of economic attention to technology change. A plethora of economic theories, methods and tools have been developed and exercised to explore a multitude of scalar properties in the analysis of technology change. For instance, there exist innumerable approaches to quantifying the *magnitudes* of various aspects of technological performance (Dayananda et al 2007). A central focus lies in techniques for deriving some *optimal balance* between contending pros and cons (Layard and Glaister 1994). Hosts of economists work on different ways to increase the *rates* at which innovation might proceed in different circumstances (Chakravorti 2001). One of the largest areas of activity concerns the *efficiency* with which organisations (firms, governments or regional agencies) may hope to foster innovation (Grupp 1997). A vibrant field of research centres on understanding regional, national or sectoral 'innovation systems' and 'market structures' in order to maximise the generic prospects for what remain largely-undifferentiated notions of innovation (Fagerberg et al 2006). And large tracts of economic literature address specific challenges posed for policy makers in seeking to design instruments for encouraging '*first movers*' (Lieberman and Montgomery 1988), '*catching up*' (Santangelo 2006), '*forging ahead*' (Abramowitz 1986), '*diffusion*' (Rogers and Rogers 2003) ,'*leapfrogging*' (Brezis et al 1993) or more general '*advance*' (Nelson and Nelson 2002) – or avoiding '*barriers*' (Parente and Prescott 1994), '*falling behind*' (Abramowitz 1986), or becoming '*laggards*' (Aghion et al 2006) or '*stranded*' (Farrell and Saloner 1986) in some particular direction of

change that is presumed to be general. Crucially, all these high-profile concepts in the economics of innovation are consonant with the unicursal (one-directional 'race') rather than a plural model of technological progress.

It is not the purpose here to denigrate the value of any of these bodies of analysis in their own right. What is striking, though, is that none of these dominant areas in the economics of technology fully address the intrinsically qualitative and political challenge posed in contemplating contending directions for change. This is not simply a matter of preference in economics for a quantitative over qualitative idiom, or technical over political problem-formulations. If this is the preference, then directionality may readily be quantified in technical terms as easily as can any of the above scalar attributes. The crucial difference is, instead, that the characterisation of innovation would then take the form of a vector rather than a scalar quantity. Unlike simple scalar numbers, vectors include the property of direction. In their plurality and relative indeterminacy, the resulting additional parameters of directionality make it far more difficult to assert a single, ostensibly uniquely objective 'way forward'. This prompts many questions of the conventional thrust of mainstream economic approaches to technology change mentioned above. For whatever reason, it seems that – despite yielding many crucial insights concerning the directionality of technology and innovation more widely – much economics is in the habit of treating these phenomena overwhelmingly in scalar rather than vector terms. This in turn provides a significant and quite specific reinforcement of the expedient political rhetorics mentioned earlier, which reduce the politics of innovation simply to an impoverished matter of 'yes or no?'; 'how much?'; 'how fast?' and 'who leads?' The prospects for rigorous attention to questions like 'which way?'; 'what alternatives?', 'who says?' and 'why?' are thus further eroded by the aggregate influence of an essentially scalar economics of technology.

Although providing no concrete substantiation for current instrumental 'one track', 'no alternatives', 'way forward', 'race to the future' rhetorics, it is in this way that much of the economics of technology currently acquiesces to this syndrome. The result is that political discourse engages with challenges in technology policy in ways that are entirely different to the manner in which we routinely debate other areas of policy. No matter how strategically expedient or highly-charged and polarised the polemics become in areas like criminal justice, education, public health or social welfare, it would in almost any political context be regarded as quite simply indefensible to accuse critics of some particular policy as being therefore generally 'anti-policy'. Yet in policy discourse across the world, this is effectively the norm on questions of technology choice. As we have seen, scepticism over the merits of particular innovation trajectories (like genetically modified foods, nuclear power or incineration of chemical wastes) is routinely branded – in the strongest terms and at the highest political levels – as generally 'anti-science', 'anti-technology' or 'anti-innovation'. The cumulative insights of economics, alongside virtually every other disciplinary understanding of technology and innovation, shows that this language is as nonsensical and disabling of critical debate as would be some hypothetical 'anti-policy' rhetoric.

In closing this examination of the neglected importance of the property of direction in the analysis and politics of technology change, there is one further observation that might be made. The transparently impoverished and instrumental character of mainstream political discourse in this field – despite the evidence to the contrary – prompts a potentially fruitful hypothesis. This arises from an insight that is well-known in anthropology, to the effect that crucial features of idiosyncratic forms of reasoning are typically best appreciated from outside. In this vein, there does exist an interesting parallel for the representations displayed in attenuated mainstream notions of technology change. This lies in the 'symbolic function' sub-stage of 'pre-operatory thought' identified by psychologists in the early phases of child development from around the age of one to three (Piaget and Inhelder 2000). The reduction of progress from a complex vector to a simple scalar is reminiscent of the restricted dimensionality in understanding of quantity conventionally associated with this style of thought. The investment of technology itself with its own effective agency seems also to parallel the animistic approach to inanimate objects documented in young children. The fixation of attention on

actuality (of emergent technological configurations) rather than potentiality (of realisable forms of innovation), also resonates with this way of thinking. Finally, the treatment of normativities as self-evident rather than as a matter for reflection is also a familiar feature of 'egocentric' cognition in early years (Elkind 1976). It is in such ways, that further understanding of conventional elite narratives of technological progress might fruitfully itself be progressed by analytically comparing this mainstream discourse with 'baby talk'.

DIMENSIONS OF DISTRIBUTION

It has been argued above that much academic and political discourse focuses disproportionately on the 'scalar' attributes of policy making on knowledge, innovation and development, such as the magnitude, rate, or efficiency with which instrumental outcomes are achieved, aggregate benefits realised or 'leadership' sustained. Yet there is one area of the literature that presents a notable exception, highlighting the importance of more complex *distributional* issues (Freeman and Soete 1997). This was a crucial focus of the 'Sussex Manifesto' in 1970 (Singer et al 1970; Ely and Bell 2009). There now exists a considerable academic literature in this field (Ely and Bell 2009; Bell 2009). Important parts of the discipline of development studies are constructed around this theme as an ordering priority. Unlike the issue of directionality, questions of distribution resonate strongly with a major strand in mainstream 'Enlightenment' notions of progress, concerning professed aspirations to democracy, accountability, empowerment, equity and equality. It might be thought, therefore, that the acknowledgement of directionality in plural processes of progress will have relatively little new to offer to existing debates over distributional issues in knowledge, innovation and development. This is partly true. But there do remain some important areas where understandings of the salient issues may be deepened and extended. There are also some further potentially significant implications for the politics of science, technology and development. These will be the focus of the present section.

It has already been discussed how concern for distributional inequalities is a theme common to both broad 'Enlightenment' notions of progress and more recent discourses around Sustainability. This dual prioritisation is reflected in the high discursive prominence routinely attached to this issue in statements from elite institutions and radical critics alike. To judge by official statements, there is ostensibly widespread formal acceptance at a global level that present patterns in the social distribution of the basic necessities for life, vital economic resources and wider cultural opportunities, are all manifestly unjust and intolerable. This is true within most countries of the world. Inequality remains the single most striking feature of our global societies taken as a whole. In seeking or professing to address these issues, however, conventional policy making on knowledge, innovation and development in both national and international contexts remains tightly circumscribed by existing patterns of power and privilege. The resulting tensions, dynamics, imperatives and opportunities are well explored in a voluminous literature. A particular challenge lies in moving away from an instrumental approach under which poverty is an 'outcome' to be 'managed'. More consistent with the 'democratic' tradition in various notions of progress and Sustainability, is that the responsibility to address poverty be seen more as a challenge of enabling political (self)-empowerment (Sen 1983). Either way, what is more relevant are the particular additional – and to many less familiar – dimensions of this responsibility that are added by acknowledging the plural nature of progress in knowledge, innovation and development. The arguments may best be outlined by focusing on the issues around technology.

The dynamics of continuously branching processes of technology choice documented in the last section constitute two major distinctive sources of additional distributional challenges. Each presents a different face of what might collectively be termed 'technological vulnerability' (Bijker 2006). The first is a social vulnerability to technology: people (and their environments and fellow beings) are perpetually vulnerable to the unforeseen, unintended, contested (and often intrinsically

indeterminate) consequences of their own technological commitments (Tenner 1997). The second vulnerability is the converse of the first: that of technology to society (Bijker 2006). Entirely feasible and viable technological pathways are themselves vulnerable to being foreclosed, especially at their incipient stages, by circumstantially (or intentionally) contrary societal forces. It is disproportionately the particular pathways for knowledge production, technological innovation and social development favoured by the poorest and most marginal groups that tend to be most irrevocably occluded. Each of these twin vulnerabilities will here be considered in turn.

In considering the vulnerability of people to technology, one key question arises right at the outset. What is so new about this? Is this not already obvious under conventional unitary understandings of progress – and variously well-addressed by conventional regulatory institutions? Even the most singular and deterministic visions of technology change acknowledge the importance of addressing adverse unintended effects. Examples might include issues associated with nuclear materials, toxic chemicals, iatrogenic disorders, urban congestion, alienating architecture, exclusive media, commodity crops, zoonotic diseases, processed foodstuffs, fossil fuels, intrusive surveillance, disabling security – and even more strongly, but often neglected weapons of mass destruction and offensive military hardware more generally. No matter how optimistically particular communities view the balances of benefits and harms for the associated technologies, each of these present prospects of severe negative impacts and seriously intractable uncertainties. And herein lies the crucial distinguishing feature between vulnerabilities as seen under conventional one-directional views of progress, and as appreciated under more plural understandings (Jasanoff 2005). The open-ended, multiply-branching nature of socio-technical change raises entirely new dimensions of indeterminacy (Wynne 1992). Where adverse 'collateral' effects are regarded as a necessary consequence of inevitable orientations for change, they become immutable conditions of existence. As exogenously determined imperatives, amelioration of such effects must be 'managed', but their very existence raises no particular issues of responsibility or accountability. Under the plural view, it is the possibilities of alternatives that render these kinds of exposures salient in relative terms as 'vulnerablities'. This in turn raises a distinctive and particularly pressing set of additional distributional issues.

Of course, all change (whether unitary or plural in its potential paths) presents challenges of uncertainty and indeterminacy. These occur even in the case of entirely natural stress and shocks, where associated adversities can be assumed to be of a generic kind – indiscriminate in their effects and undirected by any sectional interest. However, as shown with tragic frequency in earthquakes, floods, droughts, hurricanes, landslips and epidemics (where human agency is not the driving factor and there exists – in principle – no differentiation between the circumstances of rich and poor), this does not prevent impacts falling most damagingly on the least affluent and most excluded of people. Marginalisation and disempowerment force lifestyles involving greater exposure even to natural hazards: through the places people live, what they must eat and the ways they have to work. Poverty also impairs adaptive capacity, resilience and robustness. These are as true of the consequences of uncertainty over technological risks as they are in the case of natural hazards.

As in natural disasters, pre-existing social conditions of marginality and disappropriation exacerbate vulnerabilities to even the most general of the unforeseen, unintended and contested consequences of technological commitments. For instance, exposures to chemical pollution are often greatest among communities whose health is already adversely affected by poverty (Bryant 1995; Bullard 2005). Toxic waste management excludes export to poorer countries (Clapp 2001). Subsistence farmers –especially women (Jacobs and Dinham 2003) – are often so constrained in time or resources that they are unable to follow recommended practices (Waichman et al 2007). Those employed in the lowest paid jobs often face the highest occupational risks (Dwyer 1991; Lowenson 1998). Migrant workers typically operate outside health and safety law (US NRC 2003). Product usage regulations fail to account for reuse or adaptation of the kind often practised by the poorest people – or indeed to conditions of use in childrens' play (Faustman et al 2000). Those with

least resources have least capacity to avoid these kinds of harms, or remedy them where they occur. Where adverse effects of progress are regarded as inevitable but uncertain and ambiguous in their details, they present formidable problems of inequity. Where technology change is understood instead as plural and subject to social agency, the dimensions of distributional injustice are correspondingly compounded and expanded.

Beyond these relatively well-established kinds of distributional issue, however, plural understandings of progress raise a further distinctive problem. This concerns the depth of indeterminacy (Wynne 1992). As we move from unitary to plural understandings, the larger scale configuring of technologies (like those mentioned above) becomes a point at issue (Stirling 2003). The relatively confined domains of risk and uncertainty around particular incumbent trajectories are thus massively extended. This introduces additional dimensions of incertitude including deep ambiguities over the orientations of the possible pathways themselves, with associated ignorance over not only the associated probabilities and divergent framings but even the fundamental parameters of technological vulnerability (Stirling, 2008c). As discussed above, each additional dimension of incertitude impacts most acutely on those whose general circumstances lead them to be most exposed, or have least capacity to resist or adapt. The existing well-known dilemmas of risk and responsibility are thus yet further multiplied in the plural model.

All these dilemmas apply irrespective of motivations. One still further dimension added by the plural model of progress, however, are additional questions of human intentionality, social agency and tractability to power. Like indeterminacy, this applies not just in the management of the implementation of technological change, but in the configuring of the technological trajectories themselves. The problem is that the subset of possible pathways to which commitments tend to be made also tend to be selected on the basis of the balance of benefits and impacts, not across society in general, but in relation to much more particular interests. To the extent that there is a zero-sum component in human affairs in which different social actors are at least partly in competition, this alone transforms the nature of the distributional challenge. But even under a more Panglossian view (Voltaire 1759), where social actors are never attributed incentives to harm the interests of another, this dimension of intentionality in the choice of trajectories for change further massively compounds the nature of the distributional challenges associated with progress.

Here we face the second aspect of technological vulnerability: the vulnerability of technology to society. When moving from a unitary to a plural notion of progress, dimensionalities of vulnerability and inequity are significantly increased, with consequences that bear (again) disproportionately on the least powerful. It is not only the case that the poor are disproportionately vulnerable to technological choices primarily determined by the interests of the rich. It is the technological choices that might most favour the interests of the poor that are also themselves disproportionately curtailed. Viewing the evolutionary processes discussed in the last section as 'landscapes' of technological potential (Geels 2004), even quite subtle influences acting at 'watersheds' between developmental channels, can exert decisive effects on the direction of change (Waddington 1977). This presents the tantalising prospect that even apparently marginalised interests in the direction of technology change can – with luck and guile at favourable 'windows of opportunity' – entertain ambitions of being realisable. Yet this also brings its own challenges. Even at these watersheds, it is far from guaranteed that even the most concerted of social or political interventions will realise the intended ends. No matter how much more favourable some marginal branching channel may be agreed to be, it can rapidly become impossible to shift course once the formative moments have passed (Perez and Soete 1988).

Examples of widely-supported pathways that are variously claimed to favour the interests of poorer groups, and that are vulnerable in this way include: village-scale distributed renewable energy; seed production for farmer selection; low-input strategies for Sustainable agriculture; preventive forms of healthcare; socialised public transport systems; community-supported vernacular architecture

(Smith 2007) or technologies enabling nonviolent security. Of course, this vulnerability of technology to society is a more normatively ambiguous distributional issue than vulnerability of people to technology, depending as it does on evaluative judgements of the technological trajectories in question (Noble 1993). The point here is not to assert the unqualified benefits for poorer groups of any of the particular pathways mentioned above. The aim is rather to illustrate the general implications of the present analysis. In each case the move from a unitary to a plural understanding of progress raises dual facets of a new dilemma. The very possibility of empowering trajectories compounds the inequities of the intrinsically social obstacles to their realisation.

All this applies even where it is assumed that governance includes concerted and potentially effective efforts to articulate the interests of the poor in qualitative processes of pathway-creation and large-scale mechanisms of technology choice. Yet it is a pervasive feature of all the diverse understandings of plurality in technology choice reviewed in the last section, that it is usually the more proximate interests of the rich, privileged and powerful that tend to hold sway. Of course the very uncertainties, ambiguities and indeterminacies just discussed earlier mean that this may also often give rise to apparently dissonant outcomes. There is no necessary implication that privileged agency always yields more favourable outcomes for those who exercise it. Despite overwhelmingly positive health benefits of social privilege, for instance, there are many self-inflicted health disorders that are fostered by the technology and associated lifestyle choices of the rich. When distinguished from the nutritional vulnerabilities of the poor, a host of general dietary risks associated with modern processed food are more evident in high income than low income countries. Yet, even here, adverse effects fall disproportionately on those who are most marginalised within the more globally affluent populations (Wang and Lobstein 2006). It cannot be excluded that some of the consequences of these indeterminacies will serve to ameliorate maldistribution – or even improve aspects of social equity. But it would be eccentric to expect this as a general or systematic outcome.

But the main dynamic in technology choice is rather different. It is not a politically partisan point to observe that deliberate pressures for empowerment or redistribution are not the dominant drivers in key areas of global innovation activity like military technology, aerospace, energy, information, communication, robotics, nanotechnology, pharmaceuticals or neuroscience. In these as in other areas, it would be problematic simply to assume that the formative pressures acting on technology choice will necessarily be democratically progressive. In the vast arena of military research and development, the forceful assertion of particular interests is too obvious to dwell on. The opportunity costs for other areas and directions of innovation remain seriously under-discussed in current innovation policy or analytical literatures in disciplines like economics. In the vast field of agricultural innovation, innovative effort likewise focuses almost exclusively on products asserting high degrees of copy-protection by rich producers against poor farmers, like genetically modified crops and advanced hybrid seeds. Alternatives trajectories around participatory farmer breeding programmes, low-input agriculture or organic farming, or even genetic marker-assisted selection, syngenics and apomixes, remain neglected.

Likewise, worldwide patterns of innovation in public health tend disproportionately to emphasise intellectual property-intensive options like pharmaceuticals at the expenses of community- and lifestyle-based preventive care or organisational practices that may often be far more effective, but which do not allow the realising of property rents (Boldren and Levine 2008). Even in the area of pharmaceuticals, efforts focus disproportionately on addressing – and sometimes actively constructing through marketing – relatively benign health disorders of the rich, rather than tackling far more severe, widespread and (sometimes) readily remedied diseases of the poor (Doyal 2002). New areas of genetic medicine are similarly focusing on forms of 'preventive' intervention, that prioritise high revenues from large sub-populations that might be argued to be predisposed to some disorder, rather than the far smaller rewards from treating populations who actually contract them.
In transport, innovation activity disproportionately focuses on the private automobile, rather than mass transit technologies or other public transport practices. Likewise, complex forms of motive

power are preferred – like petrol-electric hybrids – partly because this allows greater value for hard-pressed manufacturers. In water systems, the internationally growing model of private sector provision is helping to reinforce innovation pathways highlighting prospects of short-term returns on higher value usage patterns. Innovations in areas like mass provision and water differentiation and recycling systems tend to be relatively neglected. All these dynamics tend to favour incumbent actors in innovation systems, potentially at the expense of more marginal innovators or even less empowered users.

The overwhelming emphasis in energy innovation is likewise still concentrated on technologies rather than behaviours, practices and organisational reform that are in many cases uncontroversially acknowledged to be far more effective and efficient (Patterson 2009). Existing concentrations of interests mean that innovation is further prioritised in supply over frequently more efficient options on the demand side. And the particular technological pathways receiving greatest support tend to emphasise highly concentrated energy production of a kind that can most readily be appropriated and controlled by similarly concentrated institutional interests. It is in this way that large scale coal power and nuclear fission, and even far more distantly-realisable forms of nuclear fusion, continue to be privileged over small, distributed, modular technologies from which incumbent interests expect innovation benefits to be more difficult to appropriate. Likewise the complex, lengthy high-volume resource supply chains associated with nuclear and fossil fuels look preferable as a source of rent to supply companies, than the typically far shorter resource supply chains associated with renewable forms of energy.

Each of these relatively well-known complexities in various sectors of technology policy raises profound distributional issues. The point illustrated here, is that the implications are significantly amplified as we move from unitary to plural understandings of technological progress. Alternative models for incentivising innovation – like the international funding of global prizes for progressive socially-determined ends – remain relatively marginal to existing governance of knowledge, innovation and development (Gallini and Scotchmer 2001). Instead, what attention there is to distributional challenges tends to focus, not so much on the detailed configuring of the directions taken by the trajectories themselves, but on (highy relevant, but relatively coarse-grain) distinctions between 'big' and 'small' or 'high' and 'low' technology (Schumacher 1998; Cozzens and Bobb 2003) or on even more restricted issues around the modalities for their respective implementation. In other words – and despite honourable exceptions – measures advocated to address injustice, reduce poverty or enhance livelihoods of marginal groups, all tend to be restricted to an essentially 'tactical' level, which presumes key features of overall strategic directions for knowledge, innovation or development – and seeks to mitigate impacts insofar as this is rendered possible under these driving assumptions. Much important wider work on distributional issues in economics, political science and development is of this kind, thus tending to neglect fundamental questions of direction in knowledge and innovation (Sen 2003; Fields 2003).

In short, there arises from this account a series of successively more demanding dimensions in the distributional challenges posed in contemplating progress in knowledge, innovation and development. These may be summarised in stylised terms as follows. First, there is the conventional attitude that might be associated with current technocratic governance discourses reviewed earlier. This is broadly supported by conventional neoclassical economics, addressing distributional questions in terms of Pareto optimisation and the hypothetical recirculation of surplus: *Only the direction favoured by dominant interests constitutes progress. Any apparent alternative would thus be inherently against progress. Overall benefits can be assumed to outweigh drawbacks. Finding the right distribution of these is largely a matter for incumbent institutions acting through existing* ***markets****.*

Second, there is a stylised view that is more sympathetic to the nature and importance of distributional challenges, but which retains an essentially unitary conception of socio-technical

progress. Various forms of this are characteristic of many of the more politically progressive areas in evolutionary, institutional and development economics: *Let's begin by defining progress as the specific direction favoured by a particular dominant view. But then, we need to ask whether (in terms that may be broader, but remain consonant with this view), overall dynamic benefits exceed drawbacks? If so, those seen to benefit might be held hypothetically to compensate those suffering drawbacks. This is then taken to justify proceeding in this direction. Only if this is not the case, might we explicitly consider alternative orientations. Deciding on this is an essentially technical matter for* ***economics****.*

Third, there is a stylised view that fully encompasses the implications of the plural model of progress outlined here. *Should we progress in this, that or some other direction? In each case, what is the distribution of benefits and drawbacks for different groups and under contrasting views? Deciding on which direction presents the right balance is inherently a matter for responsible and accountable social choice through reflexive institutions and deliberate democratic* ***politics****.* It is in the contrasts between this latter approach and the conventional progressive view identified immediately above, that we find the real significance of the plural understanding of progress for the distributional issues raised by innovation.

ENABLING DIVERSITY

This paper has made the case that moves from unitary to plural understandings of progress hold profound implications for governance of knowledge, innovation and development. An emphasis on scalar quantitative attributes of change (like 'rate', 'timing', 'efficiency', 'benefits' and 'impacts') can serve to suppress attention to crucial qualitative properties of directionality. It was argued in the last section that this adds significant but neglected dimensions to issues of distributional equity. One way of responding to these challenges is to diversify processes through which such social choices are *informed*. There exist a host of methods, practices and institutions that provide for a 'broadening out' of attention to diverse visions, issues, values, options, interests, priorities, uncertainties and perspectives in social appraisal of alternative trajectories for research, technology or development. In particular, there is a social justice imperative to ensure that these processes are as engaged with – and as sensitive and responsive as possible to – the interests and aspirations of the poorest and most marginal people. The analysis of distributional challenges in the last section amplifies this aspect, because the stakes are far higher than simply the modalities for implementing self-evidently optimal pathways of change. It is the actual directions of knowledge, innovation or development trajectories that are at issue.

This challenge of diversifying and broadening-out social appraisal can be met in a number of ways. Most obviously, there are the much-discussed, but yet-to-be-established roles for more genuinely inclusive deliberative institutions (Dryzek 2002). Examples include various forms of participatory appraisal, consensus conferences, citizen's juries, stakeholder commissions, scenario panels, extended foresight and backcasting workshops (Renn et al 1995). It is often observed that much of the apparently frenetic existing governance activity in these areas is largely motivated by instrumental pressures to justify and legitimate incumbent decision making processes and outcomes (Levidow 1999). Other instrumental rationales include the fostering of trust, the management of accountability and the hedging of blame (Hood 2002). The prominence of more ostensibly altruistic aspirations – to empower marginal groups or enhance the democratic nature of decision-making – is not always borne out in practice (Pimbert and Wakeford 2001).

Nonetheless, there can be no doubt that these emerging new forms of engagement do represent an important and potentially progressive development. They offer a significant means to diversify and broaden out the basis on which social commitments are informed (Wynne 2002). Irrespective of the presently limited institutional traction, the burgeoning of these new approaches also has the effect

of fostering new normativities, aspirations and expectations concerning the role of wider social agency in knowledge production, innovation and development (Jasanoff 2007). Real progressive political pressures are still likely to be most effectively articulated in more spontaneous political mobilisation of social movements and autonomous interventions by civil society (Pellizzoni 2001). But where these new participatory approaches become institutionalised in appropriate ways, it is possible that they may help catalyse wider engagements, and also contribute more direct tangible consequences for the trajectories followed by institutional, technological and economic change (Fischer 1990).

The benefits of these approaches are especially pronounced where they serve to 'open up' (rather than 'close down') the picture yielded to policy discourse of what constitute feasible, viable or appropriate social choices (Stirling 2008a). It is a well-established feature of most existing approaches to social appraisal aiming at informing policy on knowledge, innovation or development that they produce 'unitary prescriptive' outputs to decision-making (Stirling 2005). Instead of 'opening up' a plurality of possible recommendations to policy, each with its associated conditions, these methods instead deliver their findings as a single 'verdict', 'consensus', 'conclusion' or 'result'. In this respect, these participatory methods actually hold much in common with conventional quantitative expert-based methods of policy appraisal – like risk assessment, cost-benefit analysis or decision theory – with which they are often contrasted (Stirling 2006). These latter expert calculative methods also yield unitary prescriptive outputs to policy, but in the form of variously aggregated 'average', 'modal' or 'optimal' numerical values (Funtowicz and Ravetz 1990). In effect, all approaches to policy appraisal that deliver 'unitary prescriptive' results to decision making and wider political discourse – whether quantitative or qualitative – are founded on the usually tacit assumption that there exists (at least in principle) some definitive, broadly favourable, most preferable configuration for the decision in question. It is this presumption that the advent of these new more diverse approaches to social appraisal offers the potential to help 'open up'.

There is a need for care in making this argument. Although practice varies widely across the world, the design (if not implementation) of conventional policy appraisal methods is often clear that single definitive 'optimal' configurations will be difficult to characterise in advance, and may be misidentified. It is well known that appraisal findings are subject to many uncertainties and context dependencies. There is usually strong awareness of the ways in which ambiguities and conflicts can arise between contending perspectives, and considerable effort can be devoted to reconciling these. And dynamic rates of change are well understood to mean that recommendations may in any case become superseded by the time they are realised. The argument is that despite these important qualifications it still tends to be assumed in conventional social appraisal that (under any given context, at some specific time and subject to prevailing knowledges) a particular trajectory may in principle be assumed to be 'the best one'. This is why we find preoccupations with: the 'bottom line' in business; 'probability distributions' in risk assessment; 'optimality' in economics; 'evidence-based decisions' in policy making; 'justification' in politics and 'consensus' in participatory deliberation. All of these have the effect of promoting unitary notions of the most favourable course for future progress.

What these widespread presumptions are doing is neglecting the value and importance of diversity. This is true in three ways. First, with regard to the *inputs* to social appraisal, concerning the visions, issues, values, options, interests, priorities, uncertainties and perspectives that are included for attention. Second, diversity is suppressed in the *outputs* to decision making where 'plural and conditional' possibilities are virtually always collapsed to unitary prescriptive recommendations. The third, arguably most important, neglected role for diversity involves the more tangible *outcomes* of decision making and the subsequent institutional commitments. This concerns the variety and disparity of the strategies, policies or technologies that are actually implemented. As such, it is about the *forming* rather than the *informing* of social commitments. Instead of pursuing a single 'optimal' trajectory, we might instead deliberately seek to construct diverse portfolios of pathways, carefully

tailored to accommodate divergent perspectives, compensate for each other's weaknesses and realise complementarities. The better we understand the plurality of potentialities in human progress, the more we appreciate the severity of our neglect of the value of 'not putting all our eggs in one basket' in this way.

An example might help to illustrate what a 'diversity of pathways' might mean in practise. Perhaps the most prominent particular area where this issue is discussed in existing global governance of innovation and development is in the electricity supply sector (Bazilian and Roques 2008). There is widespread policy attention to the benefits of retaining a diversity of fuels, resources, technologies and supply chains (Farrell et al 2004). Take the case of a country that is well-endowed with continuous rainfall, displays a distributed agrarian population and extensive tracts of unsettled, under-utilised mountainous terrain – like Norway or New Zealand. Under such conditions, context-sensitive harnessing of small-scale hydroelectricity typically presents as the most favourable electricity supply option, due to the sufficient resource and strong economic, environment, social and operational flexibility benefits. Despite these virtues however, recognition for the value of pursuing a diversity of trajectories in this sector might nonetheless reasonably prompt avoidance of an over-commitment on small-scale hydroelectricity and complement this instead with some balanced mix of additional electricity supply options. This might be the case even where the complementary options are acknowledged to display individually inferior performance to hydroelectricity (Stirling 1994). The point is that the quality of diversity in the portfolio as a whole may be seen to offer a series of additional benefits that are not realised by pursuit of any single option on its own, no matter how favourable this may seem to be (Stirling 2009b). Similar considerations might lead to the pursuit of diverse portfolios of trajectories in areas like housing, agriculture, transportation, communications, and so on.

So what are these benefits on the part of deliberate pursuit of diverse portfolios of trajectories in knowledge production, innovation and development? The main argument developed in the present paper arises from the distributional issues discussed above. Where there exist divergent socio-political interests and values, it is a fundamental finding in axiomatic rational choice theory that there cannot exist – even in principle – any purely analytical means definitively to reconcile the resulting contrasting preference orderings (Arrow 1963; Kelly 1978). This refutes the value of the aggregated quantitative results routinely produced in social appraisal by methods like cost benefit analysis, risk assessment and decision theory (Stirling 2003). It also highlights that the ostensibly unitary outcomes realised in participatory deliberation may also raise issues of representativeness, contingency and legitimacy with regard to wider constituencies and discourses (Scoones and Thompson 2001). In particular, the 'closing down' of appraisal by either qualitative deliberative approaches or expert analytic methods often equally have the effect of excluding the values or interests of the poorest and most marginal people (Stirling 2008a). In such cases, where there can exist no analytic or deliberative 'fix' for irreducible political contention, the deliberate pursuit of a diversity of pathways allows divergent imperatives to be reconciled that could not otherwise be resolved (James 1990). By upholding this general value of diversity as a means to accommodate political plurality, there arises the further particular opportunity for the poorest and most marginal groups to ensure that pathways reflecting their own authentic interests and values are included in the diverse mix. The fixation on unitary 'optimal' trajectories does not so readily allow this.

A second major benefit of deliberate pursuit of a diversity of pathways arises from the crucial role of uncertainty. It has already been discussed that acknowledgement of the essentially plural nature of progress has the effect of extending and deepening the appreciation of uncertainty. Representations of knowledge move from an apparent picture of 'risk', through a less tractable state of 'uncertainty' to a more profoundly indeterminate condition of ignorance (Wynne 1992). It is with respect to these less tractable aspects of incertitude that diversity presents the most robustly practical response (Stirling 1994). Where we don't know what we don't know, then we 'don't put all the eggs in one basket' (Stirling and Mayer 2000). Diversity helps provide resilience against surprising shocks and

robustness in the face of unexpected stresses (Folke et al 2002). It does not depend for its value on any claim definitively to have characterised the problematic uncertainties (Stirling 2008). All that is required is that a diverse array of pathways be identified in relation to divergent values and interests like those just discussed. This involves pursuing a variety of disparate trajectories, balanced in relation to the apparent performance of each as viewed under contrasting perspectives (Stirling 2007a). This is again excluded by a fixation on unitary trajectories, but provided by a strategy of diversity.

A third cluster of benefits of diversity in research, innovation and development, concerns the quality of creativity and innovation itself. In detailed economic and social studies of technologies, creative activities and organisational behaviour, it is becoming increasing clear that a diversity of interconnected technological trajectories, social practices and institutional cultures can play an important role in fostering more effective and robust forms of innovation (Rosenberg 1982; Landau et al 1996). In part, this arises because diversity militates against processes of autonomy (Winner 1977), momentum (Hughes 1983) and lock-in (Arthur 1989), as discussed earlier in this paper when considering the directions of progress. By sustaining in close contact over extended periods a coherent variety of technological trajectories, social practices and institutional cultures, diversification can help catalyse many kinds of learning and cross-fertilisation (Grabher and Stark 1997). It also maintains an opportunity for options that would otherwise have been 'crowded out' to realise economies of scope and scale and more specific learning benefits of their own (Mitchell and Woodman 2006). Finally, diversity helps resist associated concentrations of institutional power that might otherwise compound the predicaments of marginal groups.

In all these ways, the quality of diversity presents particular synergies with Sustainability agendas in knowledge, innovation and development (Stirling 2008b). As was surveyed in the introductory section, the social dimension of Sustainability focuses centrally on the empowering of marginal communities and the accommodating of plural interests and values. Sustainability debates have also led to particular emphasis being placed on precautionary responses to uncertainty (UN 1992). The demanding challenges of Sustainability reviewed earlier (like poverty alleviation, climate change, biodiversity loss) also present strong imperatives for radical forms of social, technological and organisational innovation (Stirling 2008b). In addition, the emphasis of Sustainability discourse on the need for context-sensitivity highlights a further benefit of diversity as a means to more effectively respect varied local geographical, ecological, cultural or political conditions. Aspirations to single 'optimal' trajectories derived under a unitary model of progress all serve intrinsically to undermine this aspect of Sustainability. Deliberate diversification provides a means to resist this.

Having identified these various positive features of diversity, it must be remembered that, depending on the perspective, diversity also presents a number of countervailing challenges. Diversification away from what appears under any perspective to be the most favourable technology or practice necessarily involves some trade-off or compromise on performance. It is in this sense that diversity is rarely a 'free lunch' (Weitzman 1992). Likewise there may variously arise increased complexity, 'transaction costs' (Williamson 1993), loss of coherence (Cohendet et al 1992) and barriers to accountability (Grabher and Stark 1997). Where it becomes a euphemism for persistent differentials in patterns of cultural privilege – as in Apartheid South Africa – diversity can also raise serious questions over equity. The crucial challenge thus lies in striking a balance between the benefits of diversity and these countervailing considerations in the governance of knowledge, innovation or development portfolios (Geroski 1989). The value of the 'diversity premium' (Ulph 1988) that is warranted under any given perspective or context will be a function of the performance attributed to individual energy options and the contributions that each makes to system diversity (Stirling 1994). In the end, all such issues are judgemental, offering ample scope for legitimate disagreement. Recognition of these complexities underscores the importance of a systematic general framework for exploring different perspectives on the implications of energy diversity (Mercier and McGowan 1996; Bruno et al 1991).

There is also a question over the extent to which diversity may arise as an emergent consequence of technological and institutional dynamics, and the degree to which it should require deliberate governance interventions. Increasingly transnational capital flows, regulatory standardisation, trading harmonisation, market concentration and globalising governance are all exerting homogenising effects on worldwide patterns of knowledge production, innovation and development (Barry 2001; Feenberg 2002; Young et al 2006). Such developments are widely documented to be reducing global diversity in behavioural, technological and institutional configurations in areas like food production, energy services, public health, materials management, urban mobility, information and communication (Misa et al 2003). To set against this though, there remain in the world, persistent contextual variabilities, emergent differentiations and continuously randomising impulses – all of which act to resist any finality in these processes of closure (Archibugi and Michie 1997). These 'real world' complexities will always likely yield some residual degree of diversity. The particular form and vigour of deliberate intervention that may be appropriate to secure requisite levels of diversity will thus vary from context to context. There is likely to be great value in systematic and transparent frameworks for analysis and deliberation over the contending issues, and rendering the outcomes more robust and accountable. Elements of these already exist in forms that can directly support this kind of policy (Yoshizawa et al 2008). The central point is simply that an appreciation of the plural nature of progress prompts greater attention to the value of diversity as much in the concrete outcomes of technological and institutional development as in the inputs and outputs to the social appraisal of the options.

In concluding this final substantive section of this paper, it is worth returning to a theme introduced at the beginning. It was argued that many of the most problematic features of unitary models of the dynamics of knowledges, innovation and development might be traced to longstanding 'Enlightenment' notions of progress. Originating earlier and far more widely – and sustained independently in other contexts – not all these problematic features are actually specific or unique to this tradition. Nor has this tradition itself always been interpreted in the fashion of current hegemonic 'one track', 'no alternatives', 'way forward', 'race to the future' concepts of progress. Nonetheless, the Enlightenment is most often attributed with the insight that knowledge, technology and society itself might in different ways be subject to advance over time. The point that arises from the above consideration of diversity is that recent developments in social, economic and political thought around progress may now be initiating a collective insight that is as potentially momentous as the Enlightenment. The simple linear notion of *advance* is being augmented by the crucial additional concept of *direction*. A new and vastly more assertive role is thereby afforded to human agency and the (potentially) deliberate exercise of social choice. Features of the world and unfolding history that were previously deemed pre-ordained and immutable are now becoming recognised as subject to collective action. In effect, in appreciating the importance of directionality and diversity for greater realisation of human potential, we appear to be moving from mere 'Enlightenment' to more promisingly progressive 'Enablement'.

PLURALISING PROGRESS

SUMMARY OF THE ARGUMENT

The argument advanced in this paper is easily summarised. Worldwide, current hegemonic 'unitary' notions of progress allow highly specific instrumental interests and normative commitments to be represented as ontologically objective and inevitable. It is in this way that global governance of knowledge, innovation and development resounds with loudly-asserted 'one track', 'no alternatives', 'way forward', 'race to the future' rhetorics. Political discourse thus risks sinking into a tautologous and self-referential circularity in which whatever happens to emerge from dominant structures of power and privilege in existing institutions and markets is implicitly held to constitute self-evident

'progress'. The advent of high-profile political debates over Sustainability helps to address this. These emphasise the need for attention to specific normative imperatives around human wellbeing, social equity and environmental integrity. This in turn helps make more explicit and visible the inherently contestable normativity in any notion of progress, and thus the necessity for more open and deliberately evaluative political discourse. However, Sustainability debates are themselves subject to similar rhetorical processes. Normativity-excluding languages of sustainability are repeatedly used in instrumental ways to legitimate and justify manifestly unSustainable and regressive practices and outcomes.

In seeking to overcome these challenges, this paper argues for greater attention to three inherent attributes of progress: ***direction***, ***distribution*** and ***diversity***. These are as relevant to our understandings as to our evaluations of processes of change in knowledges, innovation or development. Crucially, it emerges that there is no evidence for the existence of any single uniquely-necessary pathway for change. Neither the apparent existence of regular patterns and periodicities in particular historical processes nor the manifest asymmetries in the sequencing of different configurations of institutions and technologies in any way necessarily support the one-path ('unicursal') notion of progress. Instead, wide analytical literatures spanning many disciplines present a wealth of evidence for the ways in which a range of different social, economic and political mechanisms actively shape the directions taken by progress in knowledge, innovation and social development. These processes serve to select and 'close down' around a small subset of the potentially technically feasible, economically viable and socially realisable pathways. The result is to prompt the replacement of existing mainstream unitary notions of progress with a more plural model highlighting the property of ***directionality***.

Much work in economics has contributed formatively to these insights. Yet economics as a whole persistently fixates on '*scalar*' (rather than '*vector*') understandings of progress. These suppress recognition of the qualitative importance of directionality, and so help support untenable mainstream unitary rhetorics. This in turn presents particular problems in addressing distributional issues. Attention remains focused on the scope for ameliorating the implementation of particular dominant trajectories, thus serving to help 'close down' appreciation of the diversity of alternative possible pathways for progress. This has the effect of further compounding existing patterns of inequity, exclusion and disappropriation. In order to help counter this, there exists a wide array of broader-based methods, practices and institutions for 'opening up' the social appraisal of alternative trajectories in knowledge, innovation and development. In addition, the more deliberate and explicit pursuit of diverse portfolios of such pathways offers a series of wider benefits. In various ways, these involve helping to: foster more productive and creative innovation; hedge against intractable uncertainty and ignorance; accommodate contrasting contexts and irreconcilable interests and values; and mitigate the effects of global concentration and 'lock-in'. Only through 'pluralising progress' in this way may we hope to fulfil fundamental imperatives to enable greater social agency, political equality and economic equity in knowledge, innovation and development. By 'broadening out' social appraisal and 'opening up' a more vibrant politics of choice and diversifying across a variety of disparate pathways, we may truly hope to realise the multiple dimensions of human potential.

CODA: MYTHS OF PROGRESS

One final question is prompted by this argument. How have such vibrant, diverse and enquiring global societies arrived at a situation in which mainstream understandings of progress in knowledge, innovation and development are so consistently impoverished and untenable? How can linear, deterministic 'sound science', 'pro-technology', 'way forward', 'no alternatives' rhetorics remain so under-challenged? Why are scalar attributes of progress so widely emphasised in academic analysis with so little interrogation of the crucial property of directionality? In order to better understand this rather stark state of affairs, it might be useful to return to a theme addressed right at the beginning

of this paper and briefly contemplate a broader, longer-term view. Here, an especially salient insight again comes from social anthropology, to the effect that the best way to identify key tensions and contradictions at the heart of any culture is to study the associated 'origin myths' (Nye 2003). Far from representing anachronistic survivals, these well-worked 'master narratives' (Lyotard 1984) often pinpoint the most acute sources and loci of contemporary political friction.

As already mentioned, it is often easier to appreciate such deeply challenging insights from the outside rather than the inside of a culture. It is in this self-reflective mode that we may view the well-documented situation among some herding peoples, for instance. Among the Maasai of East Africa, for instance, women tend traditionally to bear the burden of tending the cattle whilst the men enjoy most of the benefits of ownership. This is well explained and thus justified (within the cultural context) in the associated creation narrative. In this story, the women's own carelessness led them to lose the herds with which they were originally provided! If evidence is required, the narrative can point to the existence of wild beasts roaming the savannah (Kipury 1978). Likewise, the awesome powers of the medieval European church rested largely in its role as mediator of the ubiquitous imperative to atone for 'original sin'. But for the disobedience of Adam and Eve at the beginning of the World, there would have been no need for such demanding and intrusive disciplines. Any doubts were easily countered by pointing to constant threats of righteous divine retribution through ever-imminent flood, plague and famine (Deanesley 1969). Incidentally, there also arose in this tradition a similar gendered theme to that in the first example, in that contemporary privileging of men over women was also often linked to attributions of responsibility for this 'original sin' primarily to Eve rather than Adam. Either way, the same pattern is clear, in which prevailing understandings of cultural origins address the most acute axes in contemporary social tensions.

So too in modern globalising cultures might there be a significant link between active political fault-lines and our own 'master narratives' concerning the most salient features of our origins. Here however, the central tensions cluster not so much around segregated gender roles or moral control, but focus instead on modernistic notions of 'progress'. As we have seen, incumbent power structures sustain their privilege in a complex, dynamic and indeterminate world by exerting a shaping influence on the directions taken by progress in knowledge, innovation and development. The ubiquitous impact on patterns of structural change affects everyone's lives, serving as a major source of friction. In countering inevitable dissent, few resources are more disarming than deterministic understandings of 'sound science', objectivising notions of 'the way forward', disabling assertions of 'no alternatives' or consequent fatalistic resignation that 'you can't stop progress' (Norgaard 1994).
With modern notions of 'progress' then, the formative role of the creation myth lies not in the 'fall of man' but in an entirely contrasting story. This current canonically 'progressive' origin narrative was conceived, and is still celebrated, as Darwin's 'progress towards perfection' (Darwin 2004:489; cf: Richards 2005; Lewontin 2005). This remains the basis for contemporary understandings of our relationships with other life despite the equal antiquity and manifestly multidirectional orientations of advance in innumerable different species-specific trajectories (Gould 1988a). Persistently reflecting supposedly obsolete colonial prejudice, this story of inexorable evolutionary 'ascent' (Bronowski 1979) is extended to differentiate in a stratified way *between* human societies (Diamond 1998). The story is one of ever increasing scientific sophistication and technological ingenuity. This is emblazoned in the scientifically-accredited eponymous 'wisdom' of homo sapiens 'the tool maker' (Corbey 2005). Again, this is despite increasingly manifest evidence for familiar 'human-like' kinds of cognition and toolmaking in other animals that significantly blur the scientific standing of this boundary (Wynne 2001; Emery and Clayton 2004). Yet it is in this way, so the story goes, that an inexorable race along the path to modernity passed through successive ages of 'stone', 'bronze' and 'iron' – each notably defined in terms of technology (Clark 1977). Now we look forward in similar vein to futures variously defined and moulded by a cherished singularity in the orientation and staging of our knowledges and innovations: genetics, cybernetics, nanotechnology, neuroscience, astronautics, nucleonics (Allaby 1995; Berry 1999). If challenged, the evidence for both origins and destiny lies all around. Have our lives not been transformed by technological progress? Was there

ever a time when it was not a dominant force? Is innovation not accelerating at an ever-increasing pace? Does there seem any prospect for its exhaustion? Do we really want to 'go back to the Stone Age'?

As with all such origin stories, however, the picture is not quite all that it seems. Even if they are accepted as unproblematic, general acknowledgement of increasing sophistication, ingenuity and rates of change in particular directions, does not explain or justify the substance or orientations of these specific trajectories taken by knowledge and innovation. Just because a particular plant may flourish and climb at a specific spot does not mean that another might not have grown there equally well – or even better. Just because a person may acquire a degree of knowledge, experience or happiness in a chosen path of life does not preclude that these might have been matched, or exceeded, in another. Just because a traveller may journey far and learn much on one route does not mean that a different direction of travel might not have got them further or taught them more. Of course, the journey would then have fostered learning of a different kind. In a similar way, evidence for the undoubted general importance of progressive advance in human affairs says nothing of the specific merits of long term pursuit of particular directions for enquiry and understanding, or specific orientations for innovation and social change.

Talking of 'progress' in the way we do is thus akin to speaking of growth independently of form, of age independently of biography, or of a journey in terms only of the distance rather than the route. Since we have no problem articulating our experience of properties of quality and orientation in these other familiar developmental processes, there seems little reason why we should not be able to recognise essentially similar features in the general dynamics of human progress. It is in the evident attenuation of this collective ability in modern policy discourse, that we find the real discursive power of our own particular 'origin myth'. By treating knowledge, innovation and development as if they were simple 'scalar' quantities, the prevailing narrative of 'unicursal progress' neglects that these crucial areas of life also display normative 'vector' qualities, contending orientations and path-dependent histories. Different styles and directions for social, institutional and technological change may embody similar levels (if different forms) of 'progress'. This is the crucial point that is missed in current political rhetorics around 'sound scientific' decisions, 'anti-technology' cultures and 'pro-innovation' policies as 'the way forward' in the 'race to the future'.

That mainstream politics in such otherwise sophisticated societies should find it so easy to persist in this kind of 'baby talk' is testament to the gravity of our collective impairment. Our evaluative senses are dulled. Quiet voices remain unheard. A diversity of alternative futures is blinkered from sight. We need to restore these arrested social faculties. By pluralising our understandings of – and commitments to – progress, we catalyse a more vibrant, enabling and democratic politics of choice. It is only in this way that we may live up to the full promise of human potential in realising more robust, diverse and Sustainable pathways for knowledge, innovation and development.

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