TECHNOLOGY AND COMPLEXITY:
The Perspective of ASD on Complex Sociotechnical Systems, Uncertainty, and Risk

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ABSTRACT

This article argues and illustrates the important scientific role that a systems approach might play within the social sciences and humanities, above all through its contribution to a common language, shared conceptualisations, and theoretical integration in the face of the extreme (and growing) fragmentation among the social sciences (and between the social sciences and the natural sciences). The article outlines a systems theoretic approach, actor-system-dynamics (ASD), whose authors have strived to re-establish systems theorizing in the social sciences (after a period of marginalization since the late 1960s). The article applies ASD to the analysis of technology and socio-technical systems. The paper is divided into 5 parts: a brief introduction (section I) to actor-system dynamics (ASD) theory, section II conceptualizing technology and sociotechnical system and some of the problems of constraining and regulating them. Section III treats risk and risk analysis in a systems perspecctive. The paper goes on in Section IV to conceptualize risky systems, that is systems that embody risk and even the production of risk. Capitalism as a socio-economic system is used to illustrate this critical idea. Section V considers several principles which may serve to guide policy-making and regulation with respect to complex technologies and sociotechnical systems.

Keywords: actor-system dynamics, technology, sociotechnical system, risk, risky system, regulation, complexity.

I. ACTOR-SYSTEM DYNAMICS THEORY IN A NUTSHELL

1. Introduction

This article argues and illustrates that a systems approach can and should play an important scientific role within the social sciences and humanities. Above all, it can contribute a common language, shared conceptualisations, and theoretical integration in the face of the extreme (and growing) fragmentation among the social sciences and humanities and between the social sciences and the natural sciences. The challenge which Talcott Parsons (1951) and others including Walter Buckley (1967) originally addressed still faces us: to overcome the fragmentation of the social sciences, the lack of synergies, and the failure to develop a cumulative science. It aims to provide a common language and an integrative theoretical framework to mediate, accumulate, and transmit knowledge among all branches and sub-branches of the social sciences and allied humanities (Sciulli and Gerstein 1985).

In spite of a promising start and some significant initial successes, ”systems thinking” has been marginalized in the social sciences since the late 1960s (Burns 2006a, 2006b). The widespread rejection of the systems approach did not, however, stem the incorporation of a number of systems concepts into other social science theoretical traditions. Consequently, some of the language and conceptualisation of modern systems theories has become part of everyday contemporary social science: e.g., open and closed systems, loosely and tightly coupled systems, information and communication flows, reflexivity, self-referential systems, positive and negative feedback loops, self-organization and self-regulation, reproduction, emergence, non-linear systems, and complexity, among others. Institutionalists and organizational theorists in particular have adopted a number of key system concepts without always pointing out their archaeology or their larger theoretical context (Burns, 2006a).

This article outlines a systems theoretical approach, actor-system-dynamics (abbreviated ASD) whose authors have strived to re-establish systems theorizing, in part by showing how key social science concepts are readily incorporated and applied in social system description and analysis: institutional, cultural, and normative conceptualisations; concepts of human agents and social movements; diverse types of social relationships and roles; social systems in relation to one another and in relation to the natural environment and material systems; and processes of sustainability and transformation.

ASD emerged in the 1970s out of early social systems analysis (Baumgartner et al, 1986; Buckley,1998; 1967; Burns, 2006a, 2006b; Burns et al, 1985; Burns et al, 2003).[3] Social relations, groups, organizations, and societies were conceptualized as sets of inter-related parts with internal structures and processes. A key feature of the theory was its consideration of social systems as open to, and interacting with, their social and physical environments. Through interaction with their environment – as well as through internal processes – such systems acquire new properties and are transformed, resulting in evolutionary developments. Another major feature entailed bringing into model constructions human agents as creative (destructive) transforming forces. In ASD, it has been axiomatic from the outset that human agents are creative as well as moral agents. They have intentionality, they are self-reflective and consciously self-

[3] Elsewhere (Burns, 2006a, 2006b) I identify and compares several system theories emerging in sociology and the social sciences after the Second World War: Parsonian functionalism (1951), Marxist theory and World Systems Theory (Wallerstein, 2004), and the family of actor-oriented, transformative systems theories (ASD, the work of Buckley (1967, 1998), and Archer (1995) as well as Geyer and van der Zouwen (1978a,1978b).

organizing beings. They may choose to deviate, oppose, or act in innovative and even perverse ways relative to the norms, values, and social structures of the particular social systems within which they act and interact.

The formulation of ASD in such terms was particularly important in light of the fact that system theories in the social sciences, particularly in sociology, were heavily criticized for the excessive abstractness of their theoretical formulations, for their failure to recognize or adequately conceptualize conflict in social life, and for persistent tendencies to overlook the non-optimal, even destructive characteristics of some social systems. Also, many system theorists were taken to task for failing to recognize *human agency*, the fact that individuals and collectives are purposive beings, have intentions, make choices, and participate in the construction (and destruction) of social systems. The individual, the historic personality, as exemplified by Joseph Schumpeter's entrepreneur or by Max Weber's charismatic leader, enjoys a freedom – always a bounded freedom -- to act within and upon social systems, and in this sense enjoys a certain autonomy from them. The results are often changed institutional and material conditions – the making of history -- but not always in the ways the agents have intended or decided.

A major aspect of "bringing human agents back into the analytic picture" has been the stress on the fact that agents are cultural beings. As such, they and their relationships are constituted and constrained by social rules and complexes of such rules (Burns and Flam, 1987). These are the basis on which they organize and regulate their interactions, interpret and predict their activities, and develop and articulate accounts and critical discourses of their affairs. Social rule systems are key constraining and enabling conditions for, as well as the products of, social interaction (the duality principle).

The construction of ASD has entailed a number of key innovations: (1) the conceptualization of human agents as creative (also destructive), self-reflective, and self-transforming beings; (2) cultural and institutional formations constituting the major environment of human behavior, an environment in part internalized in social groups and organizations in the form of shared rules and systems of rules; (3) interaction processes and games as embedded in cultural and institutional systems which constrain, facilitate, and, in general, influence action and interaction of human agents; (4) a conceptualization of human consciousness in terms of self-representation and self-reflectivity on collective and individual levels; (5) social systems as open to, and interacting with, their environment; through interaction with their environment and through internal processes, such systems acquire new properties, and are transformed, resulting in their evolution and development; (6) social systems as configurations of tensions and dissonance because of contradictions in institutional arrangements and cultural formations and related struggles among groups; and (7) the evolution of rule systems as a function of (a) human agency realized through interactions and games (b) and selective mechanisms which are, in part, constructed by social agents in forming and reforming institutions and also, in part, a function of physical and ecological environments.

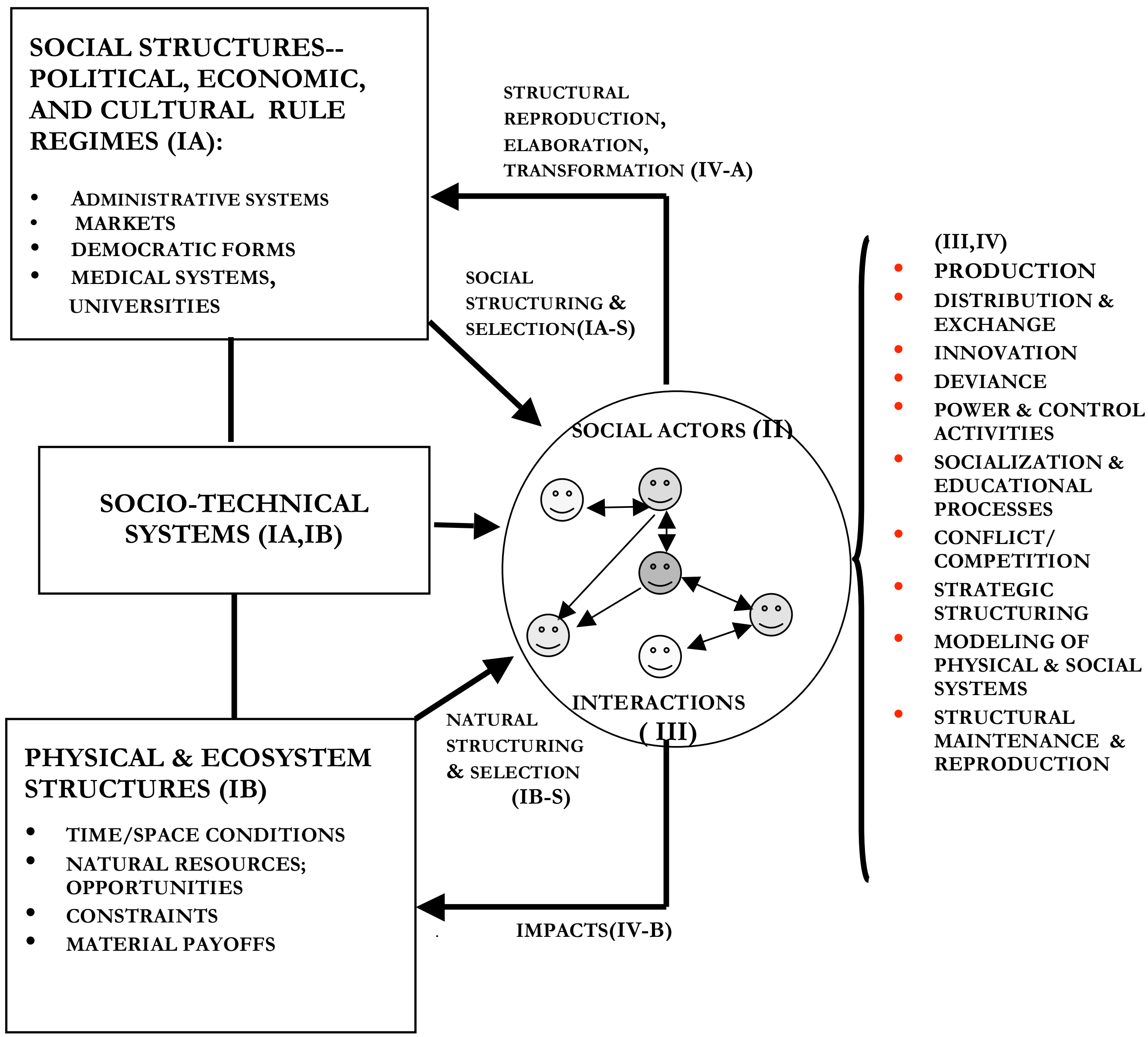
2. General Framework

Here we identify a minimum set of concepts essential to description and model-building in social system analysis (see Figure 1 below; the following roman numerals are indicated in the Figure). (I) The diverse constraints and facilitators of the actions and interactions of human agents, in particular: (IA) **Social structures** (institutions and cultural formations based on socially shared rule systems) which structure and regulate agents and their interactions, determining constraints as well as facilitating opportunities for initiative and transformation. (IB) **Physical systems** which constrain as well as sustain human activities, providing, for instance, resources necessary for life and material development. Included here are physical and ecological factors (waters, land, forests, deserts, minerals, other resources). (IA,IB) **Socio-technical systems** combine material and social structural elements. (1A-S) and (1B-S) in Figure 1 are, respectively, key **social and material (or "natural") structuring and selection mechanisms** that operate to constrain and facilitate agents´ activities and their consequences; these mechanisms also allocate resources, in some cases generating sufficient "payoffs" (quantity, quality, diversity) to reproduce or sustain social agents and their structures; in other cases not. (II) **Population(s) of interacting social agents**, occupying positions and playing different roles vis-a-vis one another in the context of their socio-structural, socio-technical, and material systems. Individual and collective agents are constituted and regulated through such social structures as institutions; at the same time, they are not simply robots performing programs or implementing rules but are adapting, filling in particulars, and innovating. (III) **Social action and interaction (or game) processes** that are structured and regulated through established material and social conditions.[4] (IV) Interactions result in **multiple consequences and developments**, intended and unintended: productions, goods, wastes, and damages as well as impacts on the very social and material structures that constrain and facilitate action and interaction. That is, **the actions IVA and IVB operate on the structures IA and IB, respectively**. Through their interactions, social agents reproduce, elaborate, and transform social structures (for instance, institutional arrangements and cultural formations based on rule systems) as well as material and ecological conditions.

In sum, ASD systematically links agency and structure in describing and analyzing social system dynamics and developments. Multi-agent conceptualizations are integrated with those of complex social systems in part through the development and application of key mediating concepts, such as social rule system, institution, cultural formation and interaction patterns. In general, while human agents – individuals as well as organized groups, organizations and nations – are subject to institutional and cultural as well as material constraints on their actions and interactions, they are at the same time active, possibly radically creative/destructive forces, shaping and reshaping cultural formations and institutions as well as their material circumstances. In the process of strategic structuring, agents interact, struggle, form alliances, exercise power, negotiate, and cooperate within the constraints and opportunities of existing structures. They change, intentionally and unintentionally (often through mistakes and performance failures), the conditions of their own activities and transactions, namely the physical and social systems structuring and influencing their interactions. The results are institutional and material developments but not always as the agents have decided or intended.

[4] Action is also constrained and facilitated by the responses of others who have the power to positively or negatively sanction, to persuade or inform. That is, the agency of some actors affects the ability of other actors to exercise their own agency. In the extreme, powerful actors can severely restrict the agency of others in selected domains of social life.

FIGURE 1: General ASD Model: The Structuring Powers and Socio-cultural and Material Embeddedness of Interacting Human Agents.



II. TECHNOLOGY AND COMPLEX SOCIO-TECHNICAL SYSTEMS

1. **Introduction**

Technologies and socio-technical systems, technological innovation and development, risk research, and issues about natural resources and environment have been key areas for ASD investigations (Andersen and Burns, 1992; Baumgartner and Burns, 1984; Burns and Dietz, 1992b; Burns and Flam, 1987; Machado, 1998, 2005; Machado and Burns, 2001; Woodward et al, 1994). Technology, as a particular type of human construction, is defined in ASD as a complex of physical artifacts along with rule systems employed by social actors to utilize and manage the artifacts. Thus, technology has both material and a cultural-institutional faces. Some of the rules considered are the "instruction set" for the technology, the rules that guide its effective operation and management. These rules have a “hands on”, immediate practical character and can be distinguished from other rule systems such as the culture and institutional arrangements of the larger *socio-technical system* in which the technology is imbedded. These latter rule systems include laws and normative principles, specifying the legitimate or acceptable uses of the technology, the appropriate or legitimate owners and operators, the places and times of its use, the ways the gains and burdens (and risks) of applying the technology should be distributed, and so on. The distinction between the specific instruction set and the rules of the broader socio-technical system are not rigid, but the distinction is useful for many analytical purposes (Baumgartner and Burns, 1984; Burns and Flam, 1987).

Such socio-technical systems as, for example, a factory, a nuclear power plant, an air transport or electricity system, organ transplantation system, money systems, or telecommunication network consist of, on the one hand, complex technical and physical structures that are designed to produce or transform certain things (or to enable such production) and, on the other hand, institutions, norms, and social organizing principles designed to regulate the activities of the actors who operate and manage the technology. The diverse technical and physical structures making up parts of a socio-technical system may be owned and managed by different agents. The knowledge including technical knowledge of these different structures is typically dispersed among different agents in diverse professions. *Thus, a variety of groups, social networks, and organizations may be involved in the construction, operation, and maintenance of complex socio-technical systems such as electrical, air transport, or communication systems,* among the systems referred to above. The diverse agents involved in operating and managing a given socio-technical system require coordination and communication. Barriers or distortions in these linkages make for likely mal-performances or system failures. Thus, the “human factor” explaining mis-performance or breakdown in a socio-technical system often has to do with organizational and communicative features difficult to analyze and understand (Burns and Dietz, 1992b; Burns et al, 2003).

The application and effective use of any technology requires a more or less shared *socio-cognitive and judgment model* (Burns et al, 2003; Burns and Carson, 2002)**.** This model includes principles specifying mechanisms that are understood to enable the technology to interact properly and effectively with its physical, biological, and socio-cultural environments. Included here are formal laws of science as well as many ad-hoc "rules of thumb" that are incorporated into technology design and use. The model of a technology includes also a social characterization of the technology, its human-machine interfaces, and its role in the larger society. This part of the model is rarely as consciously perceived or as carefully articulated as the more technical elements of the model describing interaction with the physical and biological environments.

2. Technology and Sociotechnical Systems

We consider **technology** to be a set of physical artifacts together with the rules to operate those artifacts. Thus, technology has both a material and a cultural aspect. The rules include, among others, the "instruction set" for the technology, the rules that guide its operation and management. These rules can be analytically distinguished from the institutional and cultural arrangements of the larger **sociotechnical system** in which the technology is imbedded (Baumgartner and Burns, 1984; Burns and Flam, 1987). A Socio-technical system consists of (1) the social organization (institutional arrangements) of those who manage, produce, and distribute products and services to consumers and citizens as well as deal with the hazards of production and distribution; (2) the technical professionals and networks that are animated by technical concepts and creative motivation, and fashion prototypes of machines and structures

The socio-technical system includes additional rules, laws and normative principles, specifying the legitimate or appropriate uses of the technology, the appropriate or legitimate owners and operators, the places and times of its use, the ways the gains and burdens (even dangers) of applying the technology should be distributed, and so on.

The production, use, and management activities around technologies and socio-technical systems are, of course, socially organized, for example, a factory, a nuclear power plant, an electricity or air transport system, organ transplantation system, or telecommunication network. Such sociotechnical systems consist of, on the one hand, complex technical and physical structures that are designed to produce or transform certain things (or to enable such production) and, on the other hand, social institutions, legal orders, and organizing principles designed to regulate the activities of the actors who operate and manage the technology. The diverse technical and physical structures making up parts of a socio-technical system may be owned and managed by different agents. The knowledge of these different structures may also be dispersed among different occupations and professions. Thus, a variety of groups, social networks, and organizations may be involved in the construction, operation, and maintenance of complex socio-technical systems such as electrical, air transport, or communication systems.

Technologies are then more than bits of disembodied hardware; they function within social structures where their usefulness and effectiveness is dependent upon organizational structures, management skills, and the operation of incentive and collective knowledge systems (Baumgartner and Burns, 1984; Rosenberg, 1982: 247-8). The application and effective use of any technology requires a shared **cognitive and judgment model** (Burns et al, 2001)**.** This model includes principles specifying mechanisms that are understood to enable the technology to work and its interactions with its physical, biological, and socio-cultural environments. Included here are formal laws of science as well as many ad-hoc "rules of thumb" that are incorporated into technology design and use. The concept of a socio-technical system implies particular institutional arrangements as well as culture. Knowledge of technology-in-operation presupposes knowledge of social organization (in particular, knowledge of the organizing principles and institutional rules – whether public authority, bureaucracy, private property, contract law, regulative regime, professional skills and competencies, etc. (Machado, 1998)). Arguably, a developed social systems approach can deal with this complexity in an informed and systematic way. The model of a technology also includes a social characterization of the technology and its role in the larger society. This part of the model is rarely as consciously perceived or as carefully articulated as the elements of the model describing interaction with the physical and biological environments.

The model of a technology, used in designing, constructing and operating it, describes how the technology will perform in a variety of environments. The development and elaboration of the discipline of engineering entails the articulation and elaboration of explicit models to describe and analyze technologies and their operation under different conditions. As the models become more elaborate and general, they facilitate the design of new variants of the technologies. The information contained in a model depends to a considerable degree on trial and error learning, where "experiments" with the technology in diverse natural and social environments lead to the formulation of new rules and generalizations. Continued experience and learning provides a mechanism for selection of rules (laws) that accurately describe the interactions with, and impact on, the physical and biological world. Evolutionary epistemology (Karl Popper, Donald Campbell) suggests that over time, selective pressures will cause model rules and the model itself to move towards a more accurate depiction of the physical and biological world. Of course, feedback from the physical and biological world is not the only source of selective pressure on rules. In addition, cultural biases and social power processes may inhibit the spread of more accurate rules, so there is no simple guarantee that the rules that constitute the model will evolve in the fashion suggested by evolutionary epistemology, certainly not in the short-run (Burns, 2001; Burns and Dietz, 1992). Later, we consider several factors that can cause models used in the design and implementation of technology to fail to accurately reflect reality, or to neglect factors that are nonetheless salient to the design, assessment, and operation of the technology.

In sum, the concept of sociotechnical system implies institutional arrangements and culture. Knowledge of technology-in-operation presupposes knowledge of social organization and, in particular, knowledge of the organizing principles and rules of human institutions -- public authority, bureaucracy, private property, contract law, regulative regime, etc.

3. Bounded Knowledge and the Limits of Control of Complex Technologies and Socio-technical Systems[5]

Our knowledge of complex systems -- including the complex systems that we construct such as socio-technical systems -- is inevitably bounded. Consequently, our ability to control such systems is imperfect. First, there is the relatively simple that complex systems such as radically new technologies create new ways of manipulating the physical and biological world and thus often produce results that can not be fully anticipated and understood very well in advance. This is because they are quite literally beyond the experiential base of existing models that supposedly contain knowledge about such systems. This problem can be met by the progressive accumulation of scientific, engineering, managerial, and other practical knowledge. The body of knowledge grows, even if largely as a consequence of accidents and catastrophes. However, there will always be limits to this knowledge development.

The larger scale and tighter integration of modern complex systems makes these systems difficult to understand and control. Failures can propagate from one subsystem to another, and overall system performance deteriorates to that of the weakest subsystem. Subsystems can be added to

[5] This section draws on Burns et al (2001); also, see Burns and Dietz (1992b).

prevent such propagation but these new subsystems add complexity, and may be the source of new unanticipated and problematic behavior of the overall system. Generally speaking, these are failures of design, and could at least in principle be solved through better engineering, including better “human engineering”. In practice, the large scale and complex linkages between system components and between the system and other domains of society make it very difficult to adequately understand these complex systems. The result is not only “knowledge problems” but difficulties of control, because available knowledge cannot generate adequate scenarios and predictions of how the system will behave under various environmental changes and control interventions.

First, the greater the complexity of the system, the less likely the system will behave as the sum of its parts. But the strongest knowledge that is used in many cases of systems design, construction and management is often derived from the natural sciences and engineering, which in turn is based on experimental work with simple and isolated systems. There is a lack of broader or more integrative representation. The more complex the system, and the more complex the interactions among components, the less salient the knowledge about those particular components becomes for understanding the whole. In principle, experimentation with the whole system, or with sets of subsystems, could be used to elucidate complex behavior. But in practice such experiments become difficult and complex to carry out, too expensive and risky because the number of experimental conditions required increases at least as a product of the number of components. Actual experience with the performance of the system provides a quasi-experiment, but as with all quasi-experiments, the lack of adequate control and isolation coupled with the complexity of the system makes the results difficult to interpret. Typically competing explanations cannot be dismissed. In any case, agreement on system description and interpretation lags, as the system evolves from the state it started from at the beginning of the quasi-experiment. This is one limit to the improvements that can be made in the models of these complex systems.

When a system's behavior begins to deviate from the routine, operators and managers must categorize or interpret the deviation in order to know what actions to take. This process involves higher order rules, rules about what particular rules to use ("chunking rules"). Because the exceptions to normal circumstances are by definition unusual, it is difficult to develop much accumulated trial and error knowledge of them. As a result, higher order rules often are more uncertain than basic operating rules, and are more likely to be inaccurate guides to how the system will actually behave under irregular conditions. This is another way in which complexity hinders our ability to develop an adequate understanding and control of the system.

Second, designers, builders and operators of the system are often different people working in very different contexts and according to different rules with different constraints. Each may be more or less misinformed about the rule systems used by the others. Designers may define a rigid set of rules for operators, thus allowing designers to work with greater certainty about system performance. But since the system model is imperfect, these rigid rules are likely to prevent operators from adjusting to the real behavior of the system. When they do make such adjustments – that are often useful in the local context – they are deviating, of course, from the formal rule system, and, from the viewpoint of the systems designer, can be considered "malfunctioning" components. A further factor is the length of human life and of career patterns. This makes sure that the system’s original designers are often not around anymore when operators have to cope with emergent problems, failures and catastrophes. System documentation is as subject to limitations as model building and thus assures that operators will always be faced with “unknown“ system characteristics.

Third, a hierarchy of authority creates different contexts for understanding the system and differing incentives to guide action. As one moves up in the hierarchy, pressure to be responsive to broader demands, especially demands that are external to the socio-technical system, become more important. The working engineer is focused on designing a functional, safe, efficient system or system component. Her supervisor in the case of a business enterprise must also be concerned not only with the work group's productivity, but with the highest corporate officials preoccupation with enterprise profitability, and the owners of capital with the overall profitability of their portfolio. Because most modern complex systems are tightly linked to the economy and polity these external pressures at higher levels can overwhelm the design logic of those who are working "hands-on" in systems design, construction and operation. In some cases, this may be the result of callous intervention to meet profit or bureaucratic incentives. In other cases it may be the result of innocent "drift". But in either situation, the result is much the same – the operating rules or rules-in-practice are at odds with the rules that would be more likely to optimize systems design, construction, and operation.

In addition to these macro-level interactions between the complex system and the other rule governed domains of society, there are micro-level processes at work. Managerial and other cohorts must get along with one another and accommodate each other as individuals. The day to day interaction inside and often outside the workplace makes internal mechanisms of auditing and criticism difficult to sustain. The “human factor” thus enters in in the form of deviance from safe practices, miscalculations, mistakes, and failures of complex systems.[6]

A less recognized, problem is that the processes of selection acting on rules and the processes of rule transmission will not necessarily favor rules that are accurate models of the interaction between technology and the biological and physical world. Perhaps in the very long run the evolutionary epistemology of Karl Popper and Donald Campbell will produce an improved match between the rule system of a culture and "truth" but there is no guarantee that this will occur in the short run in any given culture. Even relatively simple models of cultural evolution demonstrate that disadvantageous traits can persist and even increase in frequency. The existing structure of a culture may make difficult the spread of some rules that, whatever their verisimilitude, are incongruous with other existing rules. Nor is this necessarily a unconscious

[6] In non-industrial and especially small-scale societies, most “system” development, including technological development, involve a substantial amount of trial and error innovation. Indeed, there is probably a direct correlation between the scale of a society and the degree to which system innovation and development depends on experimentation rather than on theory. The result is that the models and much of the knowledge that guide the development and use of human constructions, including technology, tend to be rather ad-hoc and empirically based, with limited invocation of theoretical generalizations. In the modern world, and probably in most large scale societies, the systems constructed, including technological systems, often are designed not on the basis of specific models developed inductively by experimentation with prototypes, but rather from application of the rules that constitute scientific, engineering, and managerial laws or other knowledge systems which contain their own meta-rules about forms of evidence, generalization, inference and so on. While this set of generalizations has allowed a vast expansion of system development, it also results in problems associated with the limits of such models and of decontextualized knowledge in general.

process. Individuals with power may favor some rules over others, whatever their actual utility or veracity in relation to the concrete world.

Fourth, we must recognize that the idea of limited or bounded rationality applies to models as much as to people or organizations, since models are developed and transmitted by people and organizations. Human individuals and organizations use information-processing patterns that involve heuristics and biases, simplifications, rules of thumb and satisfying in searches for answers. In addition, since many contemporary systems including technologies are too complex for any single individual to understand fully, problems in model development result from the process of aggregating individual understandings into a collectively shared model. Aggregation of individual understandings and attendant models provide cross-checks and a larger pool of understanding on which to draw, and in that way the collective model will be preferable to individual models, which, even if not seriously flawed in other ways, will inevitably be incomplete. But problems of group dynamics and communication interfere with accurate modeling by a group. Groups always have agendas and dynamics that are to a large degree independent of the formal tasks to which they are assigned. These perspectives and agendas mean that there are more goals "around the table" than simply developing the best possible or most accurate operative model. Alternative goals can lead to decisions about the model construction that results in a specific model less accurate than would otherwise be possible. Delphi and other group process methods were developed specifically because of these group process problems in technological decision making.

In sum, problems of individual and collective understanding and decision-making lead to flawed models. Formal models may often be used to get past these problems, but cannot eliminate them entirely. Here we note that models are limited even when all the biases of individual and group decision making are purged from the model. A model of a complex system is typically built by linking models of simple and relatively well understood component systems. Thus, each element of the formal model is in itself a model of reality that eventually must be a translation from an individual or group understanding to a formal, explicit, possibly mathematical, understanding of that reality. For simple processes, both the understanding and the translation into a mathematical model may be reasonably accurate and complete. But not all subsystems of a complex system are well understood. This leads to a tendency to model those processes that are well understood, usually the linear and physical elements of the system, and ignore or greatly simplify elements that are not well understood. In such models "bad numbers drive out good paragraphs". As a result, human operators are modeled as automatons and the natural environment as a passive sink for effluent heat, materials, etc. In addition, the long history of trial and error experimentation with the isolated components of the system, particular physical components, has led to laws describing them in ways that are reasonably precise and accurate. This halo of precision and accuracy is often transferred to other elements of the system even though they are less well researched and cannot be subject to experimental isolation. And while some of the subsystems may be relatively well understood in themselves, it is rare that the links between the systems are understood. This is because such links and the resulting complexities are eliminated intentionally in the kinds of research and modeling that characterize most physical science and engineering. Again, the halo effect applies, and a technological hubris of overconfidence and limited inquiry may result. Finally, we should note that the model used to design and control the behavior of the system is in itself a part of the system. Since it cannot be isomorphic with the system, the behavior of the model must be taken into account when modeling the system, leading to an infinite regress.

Of course, the critical criterion for model adequacy is whether or not the model is helpful in designing and controlling the system. We acknowledge that a model, though inevitably incomplete and inaccurate, may be sufficiently complete and accurate to be of great practical use. But we also note that there are strong tendencies for such models to be more inaccurate and incomplete in describing some aspects of the system than others – particularly in describing complex interactions of components of the system, the behavior of the humans who build and operate the system, and the interactions of the systems with the natural and social environments. The failure to understand the internal physical linking of the system usually leads to more sophisticated research and modeling. The failure to understand human designers, builders and operators is labeled human error on the part of designers, builders and operators, rather than as an error in the systems model. It also calls for more sophisticated social science research and modelling.

4. Regulative Limitations in the Face of Institutional Complexity

We have suggested here and elsewhere the need for more integrative approaches. This is easier said than done. Modern life is characterized by specialization and fragmentation of knowledge and institutional domains. There is a clear and present need for an overarching deliberation and strategies on the multiple spin-offs and spill-overs of many contemporary technology developments and on the identification and assessment of problems of incoherence and contradiction in these developments.

Problems of integration are typical of many technological issues facing us today. National governments are usually organized into ministries or departments, each responsible for a particular policy area, whether certain aspects of agriculture, environment, foreign affairs, trade and commerce, finance, etc. Each ministry has its own history, interests and viewpoints, and its own "culture" or way of doing things. Each is open (or vulnerable) to different pressures or outside interest groups. Each is accountable to the others, or the government, or the public in different ways. And each is interested to a greater or lesser extent in one or more aspects of bio-diversity.

Policy formulation, for example in the area of bio-diversity, cuts across several branches of a government, involves forums outside of the government or even outside inter-governmental bodies. And in any given forum, a single ministry may have its government's mandate to represent and act in its name. This might be the ministry of foreign affairs, asserting its authority in forums which may also be the domains of other ministries (e.g., Agriculture-FAO; Environment-UNEP).[7] A variety of NGOs are engaged. Consider **agricultural-related bio-diversity**. It is perceived in different ways by the various actors involved: for instance, (i) as part of the larger ecosystem; (ii) as crops (and potential income) in the farmer's field; (iii) as raw material for the production of new crop varieties; (iv) as food and other products for human beings; (v) as serving cultural and spiritual purposes; (vi) as a commodity to sell just as one might sell copper ore or handicrafts; (vii) or as a resource for national development. In short, many different interest groups are in fact interested in it.

[7] Yet, typically the foreign ministry typically lacks the technical expertise of the specialist ministries, and this is one of the grounds for competition among ministries from the same country.

Consequently, there is considerable complexity and fragmentation of policymaking concerning bio-diversity. As (Fowler, 1998:5) stresses: "Depending on how the "issue" is defined, the subject of agro-biodiversity can be debated in any of a number of international fora, or in multiple for a simultaneously. It can be the subject of debate and negotiation in several of the UN's specialized agencies, *inter alia*, the Food and Agriculture Organization (FAO), the UN Development Programme (UNDP), the UN Environment Programme (UNEP), the UN Conference on Trade and Development (UNCTAD), the World Health Organization (WHO), the International Labour Organization (ILO), the UN Economic, Social and Cultural Organization (UNESCO), the World Trade Organization (WTO), through the UN's Commission on Sustainable Development, or through the mechanism of a treat such as the Convention of Biological Diversity. Each might assert a logical claim to consider some apect of the topic. Government agencies might pursue their interests in any of these fora, choosing the one, or the combination, which offers them the greatest advantage. Some ministries within some governments – may consider it useful to try to define the issues as trade issues, others as environmental issues, and still others as agricultural or development issues. in each case a different forum would be indicated as the ideal location fora struggle, thus framed."

"The multiplicity of interests and fora, and the existence of several debates or negotiations taking placing simultaneously, can tax the resources of even the largest governments and typically lead to poorly coordinated, inconsistent and even contradictory policies. To some extent contradictory policies may simply demonstrate the fact that different interests and views exist within a government. Contradictions and inconsistencies may, amazingly, be quite local and purposeful. But, in many cases, ragged and inconsistent polcies can also be explained in simpler terms as poor planning, coordination and priority setting. More troubling is the fact that discordant views enunciated by governments in different negotiating fora can lead to lack of progress or stalemate in all fora."

This case as well as many others illustrate the complexity of policymaking in technical (and environmental) areas. Further examples can be found in any number of areas: energy, information technology, bio-technologies, finance and banking, etc. etc. The complexity and fragmentation of the regulation environment make for risky systems. There is a need for more holistic perspectives and long-term integrated assessments of technological developments, risks, and potentialities.

5. The Politics of Science and Technology and the Scientification of Politics and Policymaking.

Science and technology are increasingly intertwined with modern politics.[8] There is a politics to

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[8] Science and technology may be distinguished in the following terms. Science is an institutional arrangement designed to produce certain types of empirical and theoretical knowledge, using particular methods, logics, etc. Technology is a set of physical artifacts and the rules employed by social actors to use those artifacts. Thus, technology has both a material and a cultural aspect. These rules are part of the "technology"; they are the "instruction set" for the technology, the rules that guide its operation. These rules can be analytically distinguished from the cultural and institutional arrangements of the larger sociotechnical system in which the technology is embedded. A socio-technical system includes rules specifying the purposes of the technology, its appropriate applications, the appropriate or legitimate owners or operators, how the results of applying the technology will be distributed and so on. The distinction between the specific instruction set and the rules of the broader socio-technical system with its social relationships are not rigid, but the distinction is useful for analytical purposes. The production, use, management, and regulation of technologies are socially organized: for example, a factory, a nuclear power plant, electricity system, transport system, intensive care unit of a hospital, an organ transplantation system, or telecommunication network. Such sociotechnical systems consist, on the one hand, of complex technical and

the question of applying new scientific and technical knowledge in technological innovation and development. There is also an increased scientification of politics itself.[9] The "politics of knowledge" concerns the application of new scientific and technical knowledge in defining and articulating policies. Issues concern, for instance, whether or not such knowledge ought to be introduced and, if so, to what extent and in which ways, and by which social agents. Although regulative issues of this sort have been around for some time (e.g. pharmaceutical products, dangerous chemicals, nuclear substances, etc.), the scale and the contentious character of knowledge politics has increased considerably.

The politicalization of technology and science is a result of the fact that the general public and political leaders have learned, and come to expect, that technology and science developments often have major, possibly negative, impacts on matters relating to health, social environment and the natural world. This has historically been a problem, particularly in the course of industrialization. As Langdon Winner (1978) argued, major technological innovations are similar to legislative acts or political foundings that establish a framework for public order that will endure over many generations. For that reason, the same careful attention one would give to the rules, roles, and relationships of politics must also be given to such things at the building of highway systems, or the introduction of the New Genetics, or the development of information and communication technology (ICT). Today the developments are highly rapid and the scale is global. Consider issues such as:

- **genetically modified foods**. Should the sale of such foods be allowed. If so, all? If not all such foods, what should be the criteria of selection? Who should determine the selections and how?
- **cloning**. To what extent should cloning be allowed. If permitted, who should be permitted to perform it, and under what conditions?
- **genetic testing and therapy**. Many major developments in this area are highly contentious. What are the risks? Since there are many uncertainties (see later), how rapidly and extensively should one proceed; which areas or applications?
- **the world wide web.** It appeared initially to be a purely promising development but which resulted in, among other things, the exploitation of its opportunities by pornographers, extremist political groups, pedophiles, etc. To what extent should the internet be regulated, by whom and in what ways?
- **global warming**: to what extent is it a genuine threat? If a threat, what are its causes and what can be done about it?

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physical structures that are designed to produce or transform certain things (or to enable such production) and, on the other hand, of social institutions, legal orders, and organizing principles designed to structure and regulate the activities of those engaged in operating the technology. the knowledge of these different structures may be dispersed among different occupations and professions. Thus, a variety of groups, social networks, and organizations may be involved in the construction, operation, and maintenance of sociotechnical systems. For any technology a model and judgment systems, even if only an elementary one, of the technology and its interaction with the physical, biological, and socio-cultural environment. The scientific and technical knowledge incorporated into the model are often developed to a greater or lesser extent. The model of the interaction of the technology with human beings and its impact on the larger society is often left partially implicit and is rarely are consciously perceived or as carefully articulated as the elements of the model describing interaction with the physical and biological environments (but even here there is no complete knowledge).

[9] This is stressed in a personal note from Nico Stehr. This paragraph articulates part of his argument.

- **creation of many large-scale, complex systems**. We can model and understand only incompletely systems such as nuclear-power plants or global, industrial agriculture,[10] global money and financial systems, etc. As a result, there are many unexpected (and unintended) developments. What restructuring, if any, should be imposed on these developments? How? By whom?.

Regulatory institutions are expected to assume responsibility for and to deal with these as well as many other developments. There is there is a sustained call for political action and regulation. This is the **politics of science and technology,** where scientific and technical expertise play a key role in providing for policymakers technical categories, descriptions, standards, assessments, etc. As a result, there is an ongoing scientification of politics and regulation. Many of the topics and issues that become the stuff of contemporary political debate, conflict and action – and are expressed in political discourses – are generated or discovered in and through science.[11] For instance, the issue of climatic change originated among scientists. This pattern is also observable in relation to the new genetic technologies. Geneticists and physicians involved in applying and developing these technologies have raised a number of ethical, legal, and political issues. At the same time, politicians depend on such technical and scientific experts in analyzing problems and defining what is the nature of the problem, what can be done, and how are the consequences or impact of different technologies to be regulated.

Since the 1960s there has been a growing concern about the social and environmental impacts – as well as the rate of change – of technological innovation and development. Changing public perceptions and assessments have emerged with respect to resource depletion, pollution, work life conditions, and employment, as well as other areas of the social and physical environments. In a number of Western societies green movements and political parties have emerged, struggling for pollution control, protection of the environment, and changes in public policies as well as social values and life styles. They refuse to accept unrestrained technological development. They attempt to set forth, not necessarily successfully, new demands and constraints relating to the application and development of modern technologies. Consequently, there is often a politics and social conflict relating to technological change and development.

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[10] Increased outbreaks of infectious diseases are associated with animal herds (pigs, cattle, chickens). An important factor in these outbreaks is the increasing industrialization of animal-food production in many areas of the world that has propelled the creation of large-scale animal farms keeping substantial number of pigs or chicken for example, in concentrated spaces. These conditions are commonly associated with a number of infectious outbreaks and diseases in the animal population, many of them a threat to human populations. Not surprisingly, this also explain the widespread use of antibiotics in order to avoid infections and to stimulate growth in these animal populations (increasing the risk of antibiotic resistant infections in humans).(Editorial (2000): "Emerging Infections -- another warning". *New England Journal of Medicine,* Vol. 342, No 17, April 27.) Today, an increased proportion of the fruits and vegetables consumed in highly developed countries is grown and processed in less technologically developed countries. The procedures to process food (e.g. pasteurization, cooking, canning) normally ensure safe products. However, these processing procedures can fail and sometimes do. One defective product may contaminate a number of individuals spread in different countries with a global food supply we encounter the risk that (see Editorial (2000): "Emerging Infections -- another warning". *New England Journal of Medicine*, Vol. 342, No 17, April 27.). The existing nationally or regionally based health care infrastructures are not prepared to handle these problems. Earlier, people were infected by food and drink, locally produced and locally consumed. We see here, in connection with technological developments, the differences between exogenous dangers and risks as opposed to endogenous dangers and risks.

[11] In this sense the scientification of political action connects with the question of knowledge politics (and policy).

In part, as a response to these movements, social learning about – and increased politicalization of – technological development is taking place. This is leading to greater recognition that:

(1)Technological innovations and the development of sociotechnical systems not only produce positive, intended effects but also negative, unintended consequences for the environment, for working conditions and employment, and for social life generally. Many of the impacts are unanticipated. As Camilleri (1976:222) has argued:

> Inventions and discoveries in such fields as medicine, communication and transport may have revolutionalized man's relationship with the natural order but they have at the same time made him the victim of these new forms of power. What is in question is not the misuse of power, widespread though it is, but the disparity in power which enables a small minority of bureaucrats, planners, and engineers to establish their technocratic rule over millions of men, and one dominant age to achieve mastery over generations yet unborn. It is not that this new race of conditioners is composed of evil men but that they have undermined their own humanity and that of their subjects by their very decision to shape humanity. In this sense, both the conditioners and the conditioned have been reduced to artifacts. Far from subduing reality to the wishes of men, the technical process of conditioning risks producing "the abolition of man.

(2) The benefits as well as negative impacts may be experienced in different time frames, and some may be purely potentialities that, given their threatening character, cannot be ignored. The immediately obvious costs may appear quite small in comparison with the intended benefits. But in the case of complex sociotechnical systems, the process of learning about and assessing consequences may be a long and difficult undertaking. It is the unintended (and often unanticipated) consequences that frequently show up as costs, having failed to be considered from the outset. By the time they are recognized, the technology is well entrenched with vested interests, an established social organization, and physical infra-structures, and appears impossible or far to costly to replace (the problem of "irreversibility").

(3) The benefits and "costs" of technologies and technological development are usually distributed unequally among groups and segments of society – as well as among generations, in the latter case leaving as a heritage in extreme cases, a polluted and depleted physical environment and shattered community structures.

(4) Individuals, groups, organizations, and social movements are increasingly alert to the possible negative impacts of modern technologies and technological developments. This may be in response to distributional effects, to environmental damage, to the depletion of resources and pollution, to the loss of jobs or meaningful work, or to the declining quality of the work environment or everyday life.

In the context of scientific and technological revolutions, new strategies and technologies of policy and regulation are required. One major proposition is that science and technology may be harnessed to enable political leaders and parliamentary bodies to play a more prominent role in relation to the development of institutional arrangements and policies to regulate the introduction and application of new socio-technical systems. In the following sections we consider technology and assessment as potentially useful tools in making public decisions and regulating technologies. However, we conclude that while these tools are useful, there is no clear-cut institutional fix, no panacea for dealing with the problems of regulating technologies and technological development. To a substantial degree, we are creating socio-technical systems, that are difficult, if not impossible, to fully know and to fully control (Burns and Dietz, 1992; Burns et al, 2001). Also, modern society is often faced with experts who do not speak with a single voice or authority.

III. RISK AND RISK ANALYSIS IN A SYSTEMS PERSPECTIVE

1. Beck's Confusions

Three factors make risk a major concept in contemporary society. (1) With modern science and engineering continually providing innovations, powerful agents can introduce and construct on a regular basis technologies and socio-technical systems, many of them having profound impacts on the social and physical environments. (2) The complexity and orginality of the innovations exceed the immediate capacity to fully know and regulate them and their impacts. In this way, human communities are confronted with systems of their own making that are not fully knowable or controllable in advance and, therefore, are likely to generate negative, unintended consequences (the "Frankenstein effect"). "Near misses," serious, unexpected problems, and accidents indicate the bounded knowledge and capacity to control such human constructions and their consequences. (3) Those managing and operating these systems learn to know them better -- in part through experience with them -- and may construct or discover better models with which to diagnose and correct malfunctionings and negative unintended consequences.[12] (4) Within modern democratic societies, there is increasing collective consciousness and critical public discussion about the limited knowledge and control capacity with respect to technology and some of the risks involved. Growing public awareness about the level of ignorance and the risks involved in the context of democratic societies contributes to the politicalization of technology and technological development and to growing skepticism about, and delegitimation of, major technological initiatives.

Several of the arguments of this article relate to those of Ulrich Beck (1992, 1997; Beck et al, 1994). Like him, we would argue that modern societies as in earlier times are confronted with many potential hazards or risks. Some of these have natural causes. Many have social causes, arising in connection with the introduction and operation of modern technologies and socio-technical systems. In Beck's perspective, Western modernization has led to a transition from an "industrial society" to a "risk society." It is confronted with its own self-destructive tendencies

[12] As we emphasize later, some of the risks of many new technologies and socio-technical systems cannot be known in advance. Operating these systems is an experiment. One learns or discovers as one goes along. In some cases, sophisticated methods and tools of analysis are required to identify risks. For instance, the use of the birth-control pill was found to entail an increased risk for blood clouts among individual users. But the increase was so small that only massive use of the pill with millions of persons revealed this factor: 30 per million dying of blood clout among users of the pill versus 5 per million among those not using the pill.

and consequences, which cannot be overcome by the system of industrial society itself. At the same time that risks are reduced in many areas – contagious diseases, poverty, unemployment, traffic accidents, etc. -- human societies are threatened with new risks – many of which can be accounted for in terms of human causality, blame, capabilities, etc. (Blowers, 1997: 855), in a word, human agency. The risks which Beck refers to are those arising from nuclear energy and nuclear waste, chemicals, genetic engineering, air pollution and the reduction of the ozone layer, among others. These have in common their potential negative consequences and their anthropogenic character (Pellizzoni, 1999).

Ironically, it is successful technology development – not its failure – which sets the stage for processes of self-consciousness and criticism, the essence of "reflexive modernity." Reflexive modernization implies self-consciousness about the limits and contradictions of modernity, for instance the complexity and ambivalent character of many of its technologies and socio-technical systems (Beck, 1997; Kerr and Cunningham-Burley, 2000:283).[13]

The limitations of Beck's perspective have been argued by many others – and it is not our intention to address here the diverse problems of the approach. Suffice it to say that Beck offers only a general and in many ways vague critique of modern, developed society, but suggests no practical prescriptions or models of what an alternative might look like, how a transformation might proceed or be achieved politically, socially, or technically (Blowers, 1997:867).[14] Beck lacks a systematic theory. He offers rather a particular perspective and a critical and provocative discourse. There are no theoretical propositions, models, or explanations. This is understandable, in part, because Beck rejects empirical sociology as a "backwater of hypothesis-testing scholars" (Beck, 1997; Kerr and Cunningham-Burley, 2000:284). In our view, a necessary condition for meaningful theory development is the identification and analysis of empirical patterns and processes. Given Beck's theoretical and empirical limitations, it is not surprising that he conflates substantially different technologies – biological, chemical, industrial, nuclear, among others -- failing to recognize or to explore different public conceptions and responses to diverse technologies (Kerr and Cunningham-Burley, 2000).

In contrast to Beck, we would not characterize modern conditions as one of high "risk" but rather one of **high risk consciousness, risk theorizing, and risk discourse**. Modern society is not necessarily more hazardous than earlier forms of society (as measured by, for instance, average life expectancy or incidence of accidents) – but it is more conscious of risks and the societal sources of risk and it regularly conducts public risk discourses and assessments.

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[13] Beck's related proposition that reflexive modernity leads principally to individualization is simply empirically false. The modern world is, rather, dominated by collective agents, organizational citizens, and major socio-political processes involving organizations (Burns, 1999; Burns et al, 2000).

[14] Beck (2000:95) sees the confrontation with risk as contributing to norm formation and community building and integration. He suggests, for instance, that if the states around the North Sea regard themselves as subject to common risks, and therefore a "risk community," in the face of continuing threat to water, humans, animals, tourism, business, capital, political confidence, etc., then establishing and gaining acceptance of definitions and assessments (and measures dealing with). Threats create a shared cognitive-normative space – space for values, norms, responsibilities and strategies – that transcend national boundaries and divisions. This can create – or lead to the creation of – active solidarity among "strangers." That is, if the accepted definition of a risk thus creates and binds – across national boundaries – cultural value frameworks (paradigms) with forms of more or less regulative responsibility – counter measures, solidarity. From whom can we expect help or alliance of and when necessary and to whom are expected to give help in a crisis or emergency.

Our approach focuses on the risks arising from new, complex technologies and the cognitive and control limitations in relation to these constructions(Burns et al, 2001; Machado, 1990, 1998). We also emphasize the importance of investigating and theorizing the particular ways in which human groups and institutions collectively conceptualize and try to deal with socio-technical systems and their consequences.[15] The argumentation is as follows:

(1)Many hazards and risks are discretionary. They are the result of human decisions and constructions. For instance, "natural death" may be avoided to a certain extent, as the result of the application of life-support technologies and intensive care medicine. Thus, "natural death" is replaced, in a certain sense, by death as human deed (although not an arbitrary one (Machado, 2000, 2002)). In general, many natural hazards are replaced by discretionary and **constructed hazards, often as unintended consequences of new technologies and their development**. "Discretionary society" is a more accurate characterization of modern conditions than the notion of the "risk society."[16] Bertilsson (1990:25) points out: "Risks have always accompanied human life. However, in earlier times the risks were **exogenous** to man and his actions. They occurred because of nature's own eruptions and man's ignorance. Today, the situation is very different: Risks are often **endogenous** to modern systems of production and living and are the result of man's own scientific-technical-industrial ingenuity in taming forces of nature. As part and parcel of the mode of production, risks are systemically produced today."

Thus, one may usefully distinguish between exogenous and endogenous risks. Risks exogenous to human actions are exemplified by natural catastrophes, for example, epidemics, volcanoes, earthquakes, hurricanes, and other natural disasters). Such catastrophes, or their threat, are beyond the control of human decisions (although human groups may still act in ways to minimize their risks – and also try to utilize magical powers to deal with such threats). Endogenous risks are those inherent to human constructions, that result in part from the unintended consequences of man's own technical and scientific ingenuity. This includes technological hazards that threaten the entire biosphere such as global warming; the release or misuse of hazardous substances such as toxic chemicals or nuclear waste; or failures of large-scale technological systems such as nuclear power plants. Adverse effects to the environment include threats to humans as well as non-human species, ecosystems, climate and the biosphere as a whole.

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[15] Miller's (1996) analysis of Durkheim and morality emphasizes the sociological perspective on moral and metaphysical risk, uncertainty about ideals that govern action and institutional arrangements (justice, democracy, welfare, socialism, etc.). Ideals may demand action involving not just risk but the virtual certainty of some sort of personal sacrifice, including life itself (as in the collective declaration of war). Or, societal risks can threaten the individual as with suicidogenic currents or currents of social pressure and conformity that sweep people off to their death, or to genocidal or other immoral actions. Thus, the risk of "killing oneself" or "killing others" for an ideal. Thus, actors may be caught up in intense, emotional convictions about the human idea, where a cause (whatever it may be) is an essential expression or realization of it – whether socialism, racial equality, environmental protection, women's liberation, or a radical form of participatory democracy.

[16] The concept stresses the discretionary powers of modern societies and their elites. It also suggests the discussions, deliberations, and judgments that go into determining what risks, how much risk, and which institutional arrangements and policies should deal with (or neglect) particular risks. In a hierarchical order, dominant actor(s) calculate from her (their) perspective and impose an order. In a more open, egalitarian system, the actors with different value orientations and risk judgments contend with one another, debate, and negotiate, that is, produce a "negotiated order."

(2) **Some technologies and socio-technical systems are much better modeled and understood than others.** In the case of known systems, one can calculate risks on the basis of established scientific models and historical patterns of performance. In the case of radically new technological developments, one proceeds in partial or almost total darkness about many interactions and unintended consequences.[17] There are always multiple consequences of an operating system S. Some of these are unexpected. They are not foreseen because of knowledge limitations, indeterminancies, or the actions of others who intentionally or unintentionally operate against intended or expected consequences (in a game-like manner). But some "knowledge" or beliefs that the actors have may be misinformed or quite wrong with respect to S and its consequences. So, previous knowledge may or may not be useful but, in any case, new uncertainties and risks arise in connection with unanticipated and unintended consequences. For instance, major dam projects have not only obvious ecological consequences but bio-medical consequences (Le Guenno, 1995). For instance, the Aswan Dam (launched in 1960 and completed in 1971) was intended to control the Nile flood, allow its water to be used more systematically for irrigation, and generate electricity. There were many unintended consequences. Silt no longer came down the Nile, and electricity from the dam had to go into manufacturing fertiliser to make up for the loss of silt. Salinisation increased in the absense of the flushing provided by the annual flood. The Nile Delta shrunk, depriving the Mediterranean of nutrients, which destroyed the sardine and shrimp fisheries. Dams, in raising the water table, typically contribute to the multiplication of insects and bring humans and animals together in new population matrices. The irrigation canal system constructed in connection with the Dam became a breeding ground for the snails that carry schistosomiasis, a disease of the liver, intestines and urinary tract that now affect the entire population in many rural areas.The increased water table and substantial bodies of irrigation water allowed mosquitos to multiply rapidly, spreading diseases such as Rift Valley fever bringing about major losses of cattle and epidemics in the human population

As stressed above, actors may operate with incomplete models of their systems, more so at certain stages than others. The models are used to identify hazards, determine their likelihood's, and make risk assessments. The attribution to certain objects, procedures or human agents as "hazards" depends on prior judgment – otherwise, risk assessors would be faced with considering every element or combination of elements in any given environment or context. There are, of course, unidentified risks. Or, risks that previously were identified but are no longer recognized. As Fox (1998:675) argues: "Inevitably, risk assessment must begin with some prior knowledge about the world, what is "probable" and what "unlikely," what is "serious," what is "trivial" or seemingly "absurd." Such judgments may derive from "scientific" sources, or may depend on "commonsense" or experiential resources. Either way, the perception of a hazard's existence will depend on these judgments. How the judgment is made (that is, what is counted as evidence to support the assessment) is relative and culturally contingent……Both risks and hazards are cultural products."

[17] Advanced societies are characterized by a "contradiction" between the forces of technological development (based on science and engineering) and the potentialities of existing institutional arrangements to provide for effective learning, knowledge production and regulation. The growing awareness and concern about this contradiction in advanced, democratic societies has resulted in questioning the authority, legitimacy, and level of risk associated with contemporary technological development. This politicalization challenges, and even threatens, the entire enterprise.

In general, in the case of the less innovative and dynamic technical conditions, agents (individuals and groups) can know and calculate risks, expected gains, and tradeoffs. In the modern world, however, environments tend to be unstable because of the dynamics of scientific and technical development, the turbulence of capitalism, diverse government interventions and regulations, and the substantial movement of peoples. There is a growing need for new analyses and new knowledge. At the same time, contemporary knowledge of nature and of social systems has never been greater.

Science and technology provide a major basis for risk definition, and for defining and systematizing many of the solutions to risk problems at the same time that innovations and further development lead to the elaboration of "risks." Thus, through contributing to new technologies and socio-technical systems, science and technology plays a crucial role in creating many of the problems and also finding solutions to the problems. In this way, it is part and parcel of the reproduction of "the risk society" (Beck, 1992; Bertilsson (1990, 1992).

Even such science is the most reliable way to produce empirical and related theoretical knowledge, the application of knowledge, e.g., in managerial and policymaking settings, entails very different conditions of reliability and certainty. These conditions are inherently contingent, offering myriad possibilities -- even under conditions of a high degree of apparent control. Large-scale disorder constrains actions, turning many human plans to naught. A major source of disorder and uncertainty arises from social opposition and conflict. However, even in the absence of human conflict and destruction, there are fundamental problems in knowing and fully regulating many major socio-technical constructions and their impacts. Thus, it is useful to approach the problem of limited knowledge and control of constructed systems, "discretionary systems", drawing on cognitive, cultural, and institutional theories (Burns and Flam, 1987, Burns et al, 2001; Machado, 1998; Nowotny, 1973; Piet Strydom, 1999).

In sum, science is essential to modern life, in defining, assessing, and regulating risks, among other things. But a new reflective stage is also needed, where science will be confronted with its own products, defects and limitations. What is needed is a "reflexive scientification" (Beck, 1992:155). A contemporary challenge is to push that reflexive theme further (Bertilsson 1992a, 27). But this implies also a politicalization of science and technology, as we discussed earlier.

2. **Risk and Risk Discourse**

Increased public concern about and political attention to environmental and technological hazards have promoted critical scrutiny of the potential negative impacts of new technologies as well as a re-assessment of older technologies. It is a challenge for modern societies that technologies, despite their countless benefits, are increasingly subject to challenge by professionals and lay persons alike. In these challenges -- and public debates and policy- processes – two separate but interrelated concepts play a central role:[18] risk and hazard (Dietz et al, 1993; LaPorte and Consolini, 1989). Hazard refers to dangers or threats which may cause adverse consequences – it is a potentiality. For instance, it may refer to the characteristics of a technology such that if it fails

[18] Risk was once (before 1800) a neutral term, referring to probabilities of losses and gains. A gamble which was associated with high risk meant simply that there was great potential for significant loss or significant reward (Fox, 1998).

significantly, the damage to life and property can be substantial. Risk is the likelihood of it doing so (Fox, 1998: 665; The British Medical Association, 1987). It is a compound measure of the magnitude of some future harmful event or effect and the probability of its occurrence. Earlier we distinguished between exogenous and endogenous risks. The exogenous risks are, of course, non-discretionary – they are beyond the capacities of those affected to change.[19] Endogenous risks depend on collective decisions and the functioning of institutional arrangements, which are human constructions.

Modern society exposes itself to risks through innovations in production (for instance, industrialization of agriculture, nuclear energy, bio-technology developments) as well as consumption (use of hydro-carbon fuels, use of chloro-fluoro-carbons (CFCs), overeating, overdrinking, smoking). Decision-makers and practitioners can influence the degree to which people are subject to risks – for instance, by managing and regulating dangers better (or worse). In this sense, they are **discretionary threats and dangers.** The safety policies and practices built into these systems are also based on collective decisions. The underlying premise is that, through choice, we can change or control risk: in other words, the level of risk is discretionary (Machado and Burns, 2003). One can choose not to develop, for instance, gene technology (or genetically modified foods), nuclear energy, or cloro-fluoride-carbons (CFCs). Or, one may choose to allow a modest, tightly regulated development. Or, one may pursue a *laissez faire* policy toward technological applications and developments. Thus, many risks are minimizable; also, they may be distributed in a variety of ways.

The new discursive ideas relating to technology and environment[20] not only entail an elaboration of risk concepts, risk accounting, risk discourses, etc. They also bring to collective awareness across space and time matters of ”choice” and ”discretion.” There are deliberations on alternative options, the negative as well as the positive consequences anticipated, their likelihoods, possible safety measures, and ways of reducing risk. Risk assessment and risk judgment are additional concepts that have become part of public discourse.

Matters of risk are being given increasing attention in sociology as well as the other social sciences and the humanities (Beck, 1992; Bertilsson, 1993, 1992, 1990; Dietz et al, 1993; Dietz and Rycroft, 1987; Giddens, 1990; Lidskog, 1994). This research has been conducted in terms of, on the one hand, “objective risk research” (that deals with the quantification of risks) and, on the other hand, “subjective risk research” (i.e. more psychological, socio-psychological, and anthropological studies of people's risk perceptions).[21] One challenge for a social science of risk

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[19] This is not strictly the case. Buildings in an earthquake zone may be constructed in ways that reduce the likelihood of material and personal knowledge.

[20] Discourses are structured in terms of a few categories (1) What are the problems, what are their causes. Here we find causal narratives; (2) Conceptions or definitions of who are knowledgeable authorities. Who has the legitimacy to define a particular problem and possible solutions. (3) Who has problem-solving responsibility and authority. That is, the authority which has the formal or informal responsibility for addressing and/or resolving the issue or problems. This is related to expertise, but is also grounded in social roles and norms for determining who should be empowered to pass judgment about problem-solving strategies or initiate necessary action on behalf of the community or polity.

[21] Bertilsson (1992a) traces the increased interest in measuring how humans themselves perceive risks to the increasing difficulties to locate proper sources of risks and dangers. It is obvious that objective risks (as calculated by technical/scientific experts) do not necessarily correspond to how people themselves perceive risks (also, see Dietz et al, 1993). Although, for instance, it is objectively more safe to fly than to go by car, most of us would probably assess the risks differently. (Bertilsson 1992a:9)

is to combine, on the one hand, the objective point of view with respect to the functioning of large-scale socio-technical systems, with, on the other hand, the subjective life-world awareness of cultural beings (Bertilsson, 1993).[22] Moreover, there are initiatives to raise the level of awareness about unknown or unspecified risks, risks yet to be identified.

3. **Risk Assessment**

The method of risk assessment is an attempt to measure, and develop accounts about, the risks associated with a technology or socio-technical system in a given context. The methods entail identifying, estimating, and evaluating risks (Fox, 1998; CCTA (UK government publication), "Management of Project Risk." Norwich: HMSO). The practitioners consider it as a technical procedure where, for a given setting, all risks may be evaluated and suitably managed – in that they all may be predicted and countered. In this way, risks, accidents, and insecurities are minimized or prevented altogether (Fox, 1998:666; Johnstone-Bryden, 1995).

Risk is open to social definition and construction, and can be changed, magnified, dramatized or minimized within a particular perspective or framework. Also, there are different, even contradictory perspectives. Insurance experts may contradict engineers (Beck,1994:11). While the latter diagnose "zero risk," the former decide a project uninsurable, because of "excessive risks." Experts are undercut or deposed by opposing experts. Politicians encounter the resistance of citizens' groups, and industrial management encounters morally and politically motivated organized consumer boycotts. Fox (1998:669) argues, "What is considered as a risk, and how great that risk is, will be perceived differently depending upon the organization or grouping to which a person belongs or identifies, as will the disasters, accidents, or other negative occurrences which occur in a culture." (also, Douglas and Wildavsky, XXX)

Technology assessment – including risk assessment – was intended as a tool for risk management. The basic idea of technology assessment (TA) was that an analyst would investigate and report on, among other things, the risk implications of a new technology or technological development. Such a study would help policymakers to decide about the appropriateness of the technology, possibly the need to redesign it, or to take a variety of necessary steps to deal with anticipated negative consequences.[23]

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[22] She states that the strength of Beck's Risk Society is that it combines these points of view, and moves simultaneously on the levels of social structure and social action, also noting the ambivalence of their interrelationships (Bertilsson, 1992:10 and 1993:5).

[23] A well-known institutional innovation in carrying out technological assessment for political leaders and the general public was the Office of Technology Assessment designed to serve especially the U.S. Congress and the general public. The Office of Technology Assessment (OTA) was established in the early 1970s and continued until the mid 1990s. It served Congress with more than 700 reports on important scientific issues. OTA testified, participated in press conferences with committee officials, gave briefings, held workshops, and conducted many other activities in support of congressional decision-making. OTA also served the U.S. public as a whole. Its studies were widely distributed and quoted by other analysts, by the professional and general press, by executive agencies, by interest groups, by individual companies, by consulting and management firms and individual citizens. Its reports provided authoritative foundations for academic research and teaching in such fields as engineering, public policy, environmental management, and international relations. Foreign countries used OTA reports to understand the USA better, as well as to provide a foundation for the decisions they had to make (the above is based on Hill (1997). OTA functioned to provide highly technical information and assessments with a minimum of bias. (One of those having experience with and at OTA, Christopher T. Hill, points out that it operated with a minimum of policy bias because members of Congress would immediately react to such bias). It was also effective in gaining access to diverse sources of information and perspective, etc. because it could claim that it was "calling in the name of Congress." One of the major limitations was that while it produced results that were of broad national interest, they were only

In the case of *well-defined and largely knowable technology and socio-technical systems*, one can identify and analyze the major impacts, "calculate" benefits and costs, and specify counter-measures. In such cases, technology assessment is a useful tool. But for most new technological developments , particularly radically new ones, information or knowledge about the likely outcomes is often very incomplete. There is a profound uncertainty about many developments and outcomes, particularly long-term ones.

In carrying out technology assessment and in ultimately managing a technology system – one requires a model. It may be simple, a very rough approximation of a functioning system and its development. Or it may be relatively well-specified and developed. Typically, not all subsystems and aspects of a complex, new socio-technical system are well understood and modeled. Those processes are modeled that are relatively well-understood. Often one ignores or greatly simplifies elements that are not well understood or unknown. Of course, a model, although inevitably incomplete and inaccurate, may be sufficiently complete and accurate to be of great practical use.

Nonetheless, bounded knowledge implies that the control of technologies and technological systems is strictly limited. Most complex, dynamic systems are particularly problematic in that there can never be complete knowledge. There will be unintended and only partly understood interactions and unintended consequences. Such complexity may lead to unexpected behavior of the system, and may cause situations in which the observers of the system including operators, technical experts, and "managers" are unable to adequately "understand" (within the working model) the system and to effectively regulate or control it. This situation is a potential sources of "dangers."

4. Risk and Democracy

The "risk society" (Beck, 1992) as a collective phenomenon is not possible in a dictatorship with censorship and suppression of thruth and a high level of collective ignorance. Of course, there are substantial risks to the social and physical environments in such societies. The dictatorship to which the population is subjected generates a variety of risks, but these cannot be publically articulated and discussed by those affected. Social order is maintained at the same time.

In a free, open society with an independent, vigorous mass media, technological developments and their negative impacts may be openly identified, debated and opposed. Public controversies about scientific and technological developments follow from the general awareness and uncertainty in the modern world with respect to issues of technology and technological development. Technological and environmental risks give rise to new kinds of social tensions and conflicts, and also imply a need for new forms of social knowledge and regulation.[24] The

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indirectly of immediate interest to Congress in helping it make decisions. Another drawback was that OTA was committed to a **form of technology assessment which tended to treat technologies as well-defined systems**. In many cases, the technologies or technology systems are not well-defined or fixed but highly dynamic and evolving. This is the case with the current development of information technologies or the new genetics, a matter to which we shall return later.

[24] Beck suggests that class awareness is fading as one becomes more preoccupied with technological and environmental risks common to all. But, empirically, this is not the case, at least not in Europe. Social exclusion is still a major issue. While the European environmental movement has put the risk issues on the political agenda, this is not the only or even the primary issue. Economic growth, unemployment, welfare, social inclusion remain major issues. And, in some cases, they are linked. Often, weaker groups are more subject to environmental and technical

democratic politicization of science and technology results in controversies that, in turn, tend to relate scientific and technical judgment to risk assessment. (Bertilsson, 1993; Sundquist 1991). Such politicalization of science and technology is characteristic of democratic society with an independent and robust mass media.

Democratic society, which may address and overcome some of the problems, has risks of its own. It may facilitate the development of widespread skepticism about, and delegitimation of, many modern systems: science, democracy, capitalism, business enterprises, markets and commercialism, the varities of technologies and socio-technical systems that may be brought under suspicion and blocked ranging from nuclear power to high power electrical lines, GMOs, nanotechnologies, biotechnologies, mobile telephones, and computer screens. Modern innovation processes are so rapid and so diverse that the testing and proper experimentation with major innovations lags behind. There is a "cultural lag."

The functioning and consequences of many innovations cannot be fully specified or predicted in advance. Of course, tests and trials are usually conducted. In the case of complex systems, however, these cover only a limited, biased sample of situations. Performance failings in diverse, in some cases largely unknown environments, will be discovered only in the context of operating in these particular environments.[25] Not only is it not possible to effectively identify and test impacts (and especially long-term impacts) of many new technologies, whose functioning and consequences are difficult to specify. But there is minimal opportunities to test complex interactions. Among other things, this concerns the impact of new technologies on human populations, where typically there is great variation in people's sensitivity, vulnerability, and absorption, etc.-- for example, new medicines impact in very different ways on diverse individuals and groups in their very different environments.

As science and technology, industries, and other complex systems are developed, new "hazards" are produced which must be investigated, modelled, and controlled. At the same time, in democratic societies, conceptions of risk, risk assessment, and risk deliberation evolve. These, in turn, feed into management and regulatory efforts to deal with (or prevent) hazards from occurring (or occurring all too much). One consequence of this is the development of "risk consciousness," "risk public discourses", and "risk policies." This situation calls forth public relations specialists, educational campaigns for the press and public, manipulation of the mass media, formation of advisory groups, ethics committees, and policy communities – that have become equally as important as research and its applications. They provide to a greater or lesser extent a sense of certainty and normative order.

IV. CONCEPTUALIZING RISKY SYSTEMS

1. Introduction

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risks than well-off groups. There are new questions of fair distribution and justice, differing from those considered earlier.

[25] Such environments may be generated in part through the very application of the technology.

Some technologies and sociotechnical systems are much more risky than others, e.g. systems of rapid innovation (Machado, 1990). This has to do not only with the particular hazards they entail or generate, but with the level of knowledge about and commitment to controlling the systems. A hierarchical society with a powerful elite may have a vision or model which it imposes, ignoring or downplaying key values and considerations of particular weak groups or overall sustainability. In other words, **their projects and developments generate risks for weak and marginal groups, and possibly even for the sustainability of the system itself over the long-run**. Typically, this may be combined with suppression of open discussion and criticism of their projects and goals. Even a highly egalitarian society may generate major risks, for instance, when agents in the society are compelled to compete in ways which drive them to initiate projects and transformations that are risky to the physical and social environment. In this sense, particular institutional arrangements such as those of modern capitalism[26] that effectively drive competition can be considered risky. For instance, new products and production processes are generated that are risky for, among others, laborers, consumers, the environment, and long-term system sustainability. Risky systems arise from the fact that institutional arrangements and professional groups are inevitably biased in terms of the values they institutionalize and realize through their operations. They entail definitions of reality and social controls that may block or prevent recognizing and dealing with many types of risks of new technologies and institutional developments.

We have many contemporary developments where scientific models and understandings of what is going on and what is likely to occur are seriously constrained. At the same time many of these developments are revolutionizing human conditions. For instance, areas of the life sciences and medicine are inspired by the modernist claims to ultimate knowledge and capacity to control human conditions (Kerr and Cunningham-Burley, 2000; Machado and Burns, 2001).[27] Consider three such developments, all of which have been launched with much promise but all of which have entailed complex ramifications and the emergence of major issues and problems not initially recognized or considered. In other words, we are increasingly witnessing new discourses about bounded rationality and risky systems (see later). Here we point to technological innovations in biomedicine that led to unintended consequences and new legal and ethical challenges of regulation.

(1) Life support technologies:
Life support entails a whole complex of technologies, techniques, and procedures organized, for instance, in intensive care units. The latter are widespread and established parts of most modern hospitals. Initially, they were perceived as only a source of good – saving lives. Over time,

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[26] Particular types of markets, super-powerful transnational corporations, regulative regimes, and many new technologies being introduced are complex, dynamic systems entailing risks.

[27] World Wide Web developments provide other examples. Internet was initially developed by academicians. Later, the idea emerged and spread of the usefulness of internet for multiple purposes. It was expected: that it would function as a pure source of unlimited information and knowledge development; that small companies and cooperatives could gain from safe access to global networks free and ideal transcultural exchange and learning could take place. But the emerging reality was somewhat different, a mixed picture. Among the unanticipated developments: internet as a zone of risk (e.g.,, from hackers) the spread of misleading information. For instance, someone may report an accident or political crisis. Others naively spread this initial report, making for a process with a non-rational life of its own; criminal activity such as child pornography, deceitful schemes, etc. ; violent political groups, neo-nazis, terrorists, etc.

however, they confronted hospitals, the medical profession, the public, and politicians with a wide variety of new problems and risks. The development has generated a variety of problematic (and largely unanticipated) conditions:

- Thousands, even hundreds of thousands of patients in advanced hospitals can be kept alive to varying degrees between life and death. Among them are those in permanent vegetative states and other forms of "coma," including "brain dead."
- Many pre-natals may be saved by modern life-support technologies but suffer severe handicaps, becoming heavy burdens for their families and the community
- The widespread application of these technologies entail very high costs and siphon resources from other forms of treatment.
- The increasing power of these technologies has made death more and more into a construction, a "deed." There has emerged a new form of death, "discretionary death" (Machado, 2000, 2002).
- There have emerged diverse ethical dilemmas and moral risks in connection with the continuing development of life support technologies.
- The cultural implications of withholding and withdrawing treatment ("passive euthanasia"), other forms of euthanasia, etc. are likely to have significant (but unknown for the moment) consequences for human conceptions and attitudes toward death.

(2) The New Genetics:

The new genetics (Kerr and Cunningham-Burley, 2000; Machado and Burns, 2001) as applied to human health problems involves an alliance of the biotechnology industry (a key part of global capitalism), scientists and clinicians from an array of disciplinary backgrounds, and policy-makers and politicians concerned with health care improvement as well cost reductions. Genetic tests providing risk estimates to individuals are combined with expert counseling so that those at risk can plan their life choices more effectively. Also, the supply of information about and control over their or their offspring's genetic makeup is heralded as a new biomedical route not only to health improvement but to liberation from many biological constraints (Giddens, 1991; Kerr and Cunningham-Burley, 2000). Kerr and Cunningham-Burley (2000:284) point out: "Advocates of the largely state-funded Human Genome Project and related commercial projects to map and sequence the human genome emphasize their progressive and objective character; promising to uncover 'the holy grail' of humanity and with it the key to eliminating and/or curing genetic diseases and disorders. The rapid application of knowledge in the clinic is further testament to the aura of certainty and social usefulness surrounding the new genetics." However, the development and applications of the new genetics is likely to lead to a number of dramatic changes, many not yet knowable at this time:[28]

[28] Already there have occurred scandals and public issues. In September 1999, there was a scandal with the death of a 18 year old patient, Jesse Gelsinger from a reaction to gene therapy at the University of Pennsylvania Institute of Human Gene Therapy. Following this case, further inspections conducted by the FDA of gene therapy trials resulted in the closure and suspension of several of those clinical trials. The reason: in many of those trials the researchers were not reporting the serious adverse events suffered by research subjects. Less than 5 percent (37 of 970) of the serious adverse events in these gene therapies were reported (see Thompson, L. (2000) "Human Gene Therapy Harsh Lessons, High Hopes" *FDA Consumer Magazine,* September-October.). Thus, in addition to demand additional reporting requirements from research groups and to promote Gene Transfer Safety symposia --and in order to restore public confidence, the FDA has proposed that all researchers doing human trials of gene therapy and xenotransplantation will post "safety" information about the clinical trials, such as side effects, adverse reactions etc. in the FDA web page (www.fda.gov).

- new conceptions of health and illness. Genetic screenings may reveal that otherwise healthy individuals are likely to become sick in the future or are carriers of potential "diseases." Many people lacking symptoms may be defined as "sick", or potentially sick, for instance those with a strong hereditary predisposition to development of breast and ovarian cancer.
- reinforcement of a shift from individual to particular types of collective illness. This makes the development closer to epidemiology and public health than to individualized and clinical treatment. Classes of apparently symptomless patients will be defined as potentially sick.
- transformation of health care organization. Genetic information obtainable with simple tests may lead to large gaps between diagnoses and available therapies.
- the emergence of new professions such as those associated with genetics, with new power and authority, is likely.
- problems of major increases in the costs of health care as well as insurance schemes.
- increasing problems (and new types of problem) of confidentiality and access to information and protection of the integrity of individuals; genetic testing offers the potential for widespread surveillance of the population's health by employers, insurance companies and the state (via health care institutions) and further medicalisation of risk (Kerr and Cunningham-Burley, 2000:284).[29]
- risks of 'backdoor eugenics' and reinforcement of social biologism as a perspective on human beings.[30]

(3) Xenotransplantation

Xenotransplantation (transplantation of organs and tissues from one species to another) began to develop in the late 80's as a possible substitute to organ replacement from human donors with the purpose of creating an unlimited supply cells and organs for transplantation (Hammer, 2001).[31] Pigs are the most likely source of such tissue and organs on a large scale. Up till now only a limited number of patients have been transplanted with pig cells on an experimental basis (Heniene et. al., 1998).[32] Xenotransplantation may lead, however, to "more than ten times the number of today's transplantations" (Hanner, 2001: 327). A constellation of public, private, and professional interests support this development even if the budget of xenotransplantation may surpass by far the costs of today's allotransplantation (Squinto, 1996)[33]. There are many uncertainties and risks not just for the patient but also for the larger community, at least according to some observers. These risks must be weighed against the importance of solving the shortage of organs for transplantation:

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[29] Such tests are useful to employers, insurance companies, and health authorities and welfare services, since they would allow them to limit their liabilities, target future services for specific 'at risk' groups, and emphasize personal responsibility for disease alleviation and prevention (Kerr and Cunningham-Burley, 2000:289).

[30] A new biological language is being developed. It is more politically correct than older languages such as that of "racism." Also, cognitive abilities" replaces the older and politically fraught concept of "intelligence." New, broader continuums of disease have been established (such as the "schizophrenic spectrum" (Kerr and Cunningham-Burley, 2000: 296).

[31] Hammer, C. (2001) "Xenotransplantation: perspectives and limits". *Blood purification* 19; pp.: 322-328.

[32] Heniene W., Tibell A, Switzer W, et. al. (1998) "No evidence of infection with porcine endogenous retroviruses in recipients of porcine islet-cell xenografts". *The Lancet*; 352; pp.: 695-99.

[33] Squinto, S. (1996) Xenogeneic organ transplantation. *Current Opinion in Biotechnology* 7; pp.: 641-645.

- The risk of "xenosis" (interspecies transmission of infectious agents via xenografts) has the potential to introduce infectious agents into the wider human community with unusual or new agents. This is also the case in connection with transgenic pigs (pigs manufactured with human genes in order to reduce rejection by the immunity system of the patient) and patients with compromised immunity (QJM Editorial, 2000).[34]
- To the risk of viral infections (endogenous retroviruses) must be added other possibly infecting organisms. Ensuring pathogen-free pigs for transplantation will require a complex safety system throughout the entire process, including organ procurement and transportation. A large scale system may have difficulties in providing such a guarantee. "In the US …even a risk as low as 1% could mean that hundreds of infections occur every year" (Collignon, 1998)[35]
- Given the ethical issues involved in xenotransplantation for, among others, the "donor" animals and the risk of further provoking animal rights movements is not negligible. This may reinforce a hostile social climate that spill over and affect other areas not just concerning animal welfare but also biotechnology in general.[36]
- Cultural and psychological risks of using animal parts in general and pigs in particular.

These high-tech developments – life support technologies, the new genetics, and xenotransplantation -- have evoked public comment and discussion, more in some cases (the new genetics) than others (xenotransplantation or life-support technologies and changing end-of-life practices). Also, proponents have often engaged in systematic efforts to "inform the public" and to establish "ethical controls" and "greater accountability" for scientific and technical initiatives in order to offset or neutralize potential critique and opposition that might arise. [37]

Conventional technology assessments fail in the face of technology developments where many important consequences and further developments cannot be specified beforehand. This is, in part, a result of the limitations of the method. There are also problems of legitimacy and the growing awareness of the need to engage a variety of stakeholders. Technical experts often disagree among themselves, as pointed out earlier. Stakeholders may or may not succeed in identifying what are the "significant" implications for them. Since their values and concerns are the point of departure, identifying such dimensions is important. But often they have difficulty in identifying initially many of the relevant values involved, a failure that can have serious consequences (*Lancet*, "Policy and People," 2001: 357).[38]

In sum, technology assessment as a universal tool for calculation and prudential judgment is very limited for innovations such as those outlined above. In the face of radical technological innovations where knowledge is incomplete and fuzzy, one is forced to adopt an "experimental"

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[34] Editorial (2000) "Xenotransplantation: postponed by a millennium?" *QJM. Monthly Journal of the Association of Physicians* 93; pp. 63-66.
[35] Collignon, P. (1998) Correspondence: "Safety of xenografts" *The Lancet*; 352: 9137.
[36] "Techno-Utopianism"; "Who plays God in the 21st century?" Turning Point Project. http://www.turnpoint.org/
[37] Law and administration are to a certain extent unreliable regulators, especially in high tech and rapidly developing areas (Machado and Burns, 2001). This explains, in part, the extraordinary expansion of ethics as a basis of regulating, among other things, risks of scientific and technological development. The question of accountability in relation to modern risks is a complicated but an urgent matter to resolve.
[38] Policy and People (2001) "FDA wants more disclosure of gene therapy and xenotransplantation risks" *The Lancet*; 357:.

attitude; one monitors developments and re-iterates discovery, definition, and assessment processes. Broader discussions, debates, and joint analyses are essential.

While technology assessment was initially seen as a technical matter, critics as well as practitioners have come to emphasize the need for greater "participation" of non-experts and those affected or likely to be affected by the technology. One obvious reason for this is to bring into the process participants who could identify or articulate important values and consequences which would, otherwise, be missed by technical experts. This provides for a more common point of departure for any risk and technology assessment. In short, the emphasis is on extensive participation that go beyond the narrow limits of a technical or scientific community. But given the range of values and considerations activated in such processes, there is a need for organizing more multi-dimensional and integrated assessments, hence the emergence of "integrated assessment models" which entail bringing together, for instance, "focus groups" involving actors representing different perspectives and value orientations.

In sum, a socially and politically important class of socio-technical systems are defined by LaPorte (1984, 1977) as benefit-rich but hazardous. We construct and use such systems precisely because of their great benefits. But they entail substantial risks: for example, nuclear power plants, nuclear waste storage systems, etc. A critical goal for such systems is to avoid operational failures altogether – hence the attention to constructing and maintaining highly reliable organizations (HROs). Thus, these reliable systems, even if they entail substantial hazards, are supposed to be low risk. When successful, they are characterized by a capacity to provide expected levels and qualities of services with a minimum likelihood of significant failures that risk damage to life and property (LaPorte, 1984). Hence, a potentially hazardous system is designed and operated to be a low risk system.

2. The Unregulated Production of New Risks

In a systems perspective (also, macro-sociological), one is driven to move away from reductionist approaches to risk toward more systemic perspectives. Modern capitalism – with its powers and mobilizing capabilities – generates risks. Therefore, not only are there risky technologies, policies, and social practices, which in an ever-increasingly complex world cannot be readily assessed or controlled, but there are **risky systems of production,** generating risky technologies, policies, and practices (Machado, 1990). In highly complex and dynamic systems, some hazards cannot be readily identified, and probabilities of particular outcomes cannot be specified and calculated. It follows that some risks cannot be determined beforehand. This is in contrast to cases of well-known, relatively closed technical systems, where one can determine all or most possible outcomes and their probabilities under differing conditions and, therefore, calculate and assess risks. Also, some negative consequences arise because values of concern to groups and communities are not taken into account – as a result of the prevailing power structure – or are never anticipated because of the limitations of the models utilized by power-wielders.

Several key dimensions of risky system can be specified, for instance: (i) Systems with high capacities to affect the physical and social environments – that is, powerful systems -- are in a position to threaten or cause harm to key values (concerning, for instance, the physical environment, social order, welfare, etc.); (ii) Hierarchical systems where elites and their advisors adhere to with great confidence, and implement, abstract models which, on the one hand, have ideological or moral meanings but entail, on the other, radical impositions on the social and physical environment. Developments are decided by an elite certain of their values and truth, and ignoring or neglecting other value orientations and interests, for instance, those populations subordinate to or dependent on it; (iii) Agents may be operating may be operating in a highly competitive context which drives them to initiate projects and carry through social transformations generating major risks for the social and physical environments. In general, “competitive systems" drive experimentation, innovation, and transformation (Burns, 2001). That is, institutional arrangements and related social processes generate -- or at least tolerate the application of -- dangerous technologies and socio-technical constructions. Forms of modern capitalism combining hierarchical arrangements (the corporate structure of the firm) with institutional incentive systems (“the profit motive”) entail such risky structural arrangements. Economic agents are driven toward excessive exploitation of natural resources, risky disposal of hazardous wastes, and risky technological developments (exemplified by forms of advanced industrial agriculture which in Europe resulted in the production and spread of “mad-cow disease”). Capitalism, the modern state together with science and technology transform nature (untamed, unknown) into an environment of resources which can be defined in terms of prices, exchange-values and income flows. In many areas, this is a risky business (and indeed, the capitalist machine’s ultimate limitation is probably the physical environment and available resources) (Burns et al, 2002; DeVille and Burns, 1976). But capitalist wealth can also be mobilized to criticize and delegitimize the criticisms of, for instance, environmental scientists and movements that struggle to limit certain capitalist developments and to buy off governments that are inclined to regulate. (iv) Even if knowledge about the systems is high (which may not be the case), it is bounded knowledge. There will be unanticipated and unintended consequences which cause harm or threaten to harm to particular groups as well as to society as a whole. (v) There is a low level of reflectivity about the bounded knowledge, unpredictability, problems of unanticipated consequences. Feedback is low, learning fails to take place, for instance, with respect to some of the negative impacts on the social and physical environments. Such systems generate risks -- -- possibly beyond the capacity of institutions to learn fast enough about and to reflect on the changes, their likely or possible implications for the physical and social environments, their value or normative implications and the appropriate strategies for dealing with them.

Modern institutional arrangements and their practices *combine different types of selective processes, which may encourage, or at least not constrain risky behavior*, having extensive and powerful impacts on the physical and social environments, for instance, industrial developments, transport systems, nuclear power facilities, electrical networks, airports, etc.). Thus, a transport system structures the socio-economic environment of, for example, enterprises engaged in market activity. A well-developed transport system connecting most parts of a region means that no enterprise can effectively pursue a local strategy (for instance, ignoring the fact that outsiders can now penetrate the local market with ease, or local customers can readily reach companies in other parts, becoming potential customers). Thus, the technology of the transport system operates selectively to encourage companies that conduct business more regionally or globally (as well as those companies that identify and orient themselves to particular niches).

High cohesiveness and integration of professional and occupational groups also may contribute to making systems risky by biasing and distorting the production and interpretation of system knowledge. A profession is characterized by a number of patterns and social practices which maintain and reinforce particular definitions of reality often in the face of contradictory evidence (concerning such cognitive equilibration, see Machado, 1998). In this way, even the most rational modern collectivities may be trapped into biases, distortions, half-truths, delusions, and rationalizations. Information selectivity and denial, re-definition and re-interpretation of situations, definitions as irrelevant of particular situations, events, and developments or data sources – as irrelevant. Such factors play a major part in maintaining a type of solidarity in and integration of a community – and a particular definition of reality. They also operate among professionals and organizations oriented to empirical science, "truth", and rationality. All communities share in common that they are held together -- and social order maintained -- through cognitive balancing mechanisms, grounded in rituals, special discourses, props, and situational structures within groups and organizations (Machado, 1998). In this sense scientific discourses, rituals, props, and organizational arrangements can be -- and are -- used in magical and mythical ways (Elias, 1996). **And this makes them also risky producers of knowledge and sources of biased assessments and judgments**. Nevertheless, policymakers and operators must rely on them.

3. The Case of Capitalist Productive Forces: Creating, Introducing, Spreading

Modern capitalism together with the natural and technical sciences is a powerful engine of change, generating revolutionary powers and transforming the conditions of life: economic, technological, social and environmental. Dynamic capitalism is characterized by its freedoms (or minimal constraints); its acquisitive spirit (the pursuit of economic interests) but also its capacity to accommodate and to symbiosise with diverse interests and values; the opportunities it provides for “positive-sum games” (with enforceable rules); its effective forms of power and control; and its competitive mechanisms. Briefly, (1) **Its multiple freedoms**: There is not only the freedom to trade and to initiate new products and forms of production, or to commodify new goods and services and to penetrate new areas and establish commodity markets, but the freedom to create and adapt new forms of extended cooperation and organization (joint stock company, joint ventures, franchises, etc.) and also the freedom to compete (which is highly constrained in many groups and communities) . Also, there is a general lack of constraint – or the constraints are minimal – on the accumulation of wealth and power, hence the substantial tendencies to monopoly or oligopoly in many areas. (2) **The acquisitive spirit and more**: Capitalist forms provide opportunities to pursue multiple interests (that far exceed the mere interest to pursue wealth (a form of generalized power)): for instance, the interest in sociability and cooperation with others or in competition with others, the interest in exercising power and control over others, in doing something useful such as producing a valuable good or service, or creating a new good or service; the interest in trying out an idea or starting a project with others, in providing jobs and opportunities for others, or in generating wealth for good causes. That is, capitalist forms can accommodate an extraordinary range of material and ideal interests, direct and indirect. And, indeed, the wealth generated by capitalism may support many values necessary or important to human life including family life, welfare, education, music, art, religious institutions, and spirituality. Nonetheless, the strongest value – which is built into its institutions, for instance its accounting system (see later), is money value; its power and control mechanisms are mainly directed at gaining and expanding (or avoiding the loss of) money wealth. (3) **Power and control**: Capitalism through enterprises, contracts, franchises, and other legal forms provides for a high degree of control and regulatory potential. Substantial power can be exercised over human beings and resources in organizing and directing production; knowledge and expertise can be mobilized to innovate in creating new technologies, techniques and forms of cooperation and organization. The wealth generated by capitalist endeavors (as well as the knowledge and organizational capacities) are of interest to states and can be used to influence policy and politics as well as other domains of society (Baumgartner et al, 1979). Through its generation of wealth and its freedom to innovate in technologies, techniques, and strategies, it is capable of dramatically changing societal conditions but also circumventing or breaking out of many of the constraints imposed by regulative regimes, for instance those established by the national state (see later discussion).

. Capitalist systems not only produce goods and services and facilitate the continuation of capital accumulation. But they tend to produce and reproduce social power relations and uneven development, advanced as well as backward sectors, wealth as well as poverty, cooperation and conflict with respect to the conditions, products, and development of capitalism. Many of these developments in a capitalist system, if uncontrolled or unregulated, would undermine or destabilize it. Historically, particularly since the Industrial Revolution, the capitalist system in both its national and international forms, has experienced a number of economic and political crises which destabilized it: for instance, deep depression, hyper-inflation, escalating capital-labor conflicts, and major socio-political movements aimed at radically transforming capitalism or even eliminating it. Its very survival was threatened in some instances. Its history has been characterized by the process of innovative attempts to create and develop state as well as private regulatory mechanisms designed to counteract or overcome failures and instabilities of capitalism (Baumgartner et al, 1986; Burns, 1997; DeVille and Burns, 1976; Burns et al, 1987). In dealing with crises, many capitalist societies have shown a remarkable ability to promote strategies and to design societal (that is, economic and political) regulatory processes operating to maintain or reinforce system stability and legitimacy.

ASD stresses then the importance of regulative (in many cases non–economic) institutions and conditions essential to stabilizing capitalist institutions and maintaining a **virtuous circle of capitalist growth and development**. Given substantial variation in institutional and cultural conditions, it is not surprising that a variety of different but more or less effective and expansive capitalist arrangements have been developed. Thus, capitalism has taken significantly different forms in countries and regions such as Austria, Canada, Chile, England, France, Germany, Italy, Japan, Russia, Sweden, the USA, etc.). This variation is captured by the notion of the social embeddedness of economic processes (Baugartner et al, 1986; Granovetter, 1985; Hollingsworth and Boyer, 1997).

The ASD model of socially embedded capitalism specifies the following array of mechanisms (Baumgartner et al, 1979, 1986; Baumgartner et al, 1979; Burns, 1985, 1987, 2000; Burns et al, 1987), briefly:

(1) The complex of capitalist institutions organizes the social processes of economic production, distribution, and exchange in particular ways, which generate multiple outcomes and developments. The latter include diverse effects in the sphere of economic production and market exchange (“spin-offs”) as well as in other spheres such as the social, environmental, and political (“spill-overs”).

(2)Actors or classes of actors have qualitatively and quantitatively different linkages to, and claims over, the gains from spin-offs and spill-overs (and also, differential linkages and disclaimers with respect to costs or burdens and risks); this patterning is based on their positions or roles in the division of labor and on their differential possession of property and other control rights.
(3)The capitalist institutional arrangements make not only for unequal acquisition but for sustained unequal accumulation of capabilities, resources, and social powers among different actors or classes of actors, given their differentiated positions with respect to production, distribution, and exchange. The more promising, entrepreneurs, enterprises, sectors, expansive regions, and nations attract (or gain access to) resources and investments. The stagnant, marginal agents and areas are denied or loose access to resources. In general, the distribution of benefits and costs of production and exchange processes under such institutional arrangements are unequal and tend to increase inequality over time. In the absence of regulation or control, extreme concentrations of economic power and wealth are generated, as power attracts as well as begets power.
(4) These inequalities lead, in turn, to systematically differential capacities to take advantage of and shape productive opportunities as well as to avoid or overcome burdens and cost traps and the vicious circles of stagnation and decline (see below).[1] Thus, power differences and uneven development capabilities tend to be reproduced and elaborated, other things being equal. One of the characteristic features of capitalist systems is that they not only entail but generate unequal power structures.
(5) Such systems are human constructions and require continual managing and structuring activities in response to changes in their environments as well as in response to internal developments – system reproduction depends then not only on replacing the means of production and the labor force but also entails appropriate structuration of the political and socio-cultural contexts for purposes of legitimizing and stabilizing capitalism.
(6) Capitalism as any complex system generates a number of unanticipated and unintended spin-offs and still-overs, many of which cannot be known or predicted beforehand because of bounded knowledge or limited modeling capacity with respect to such complex systems. Some unintended spilloffs and spillovers operate to destabilize or undermine capitalist institutional arrangements. Destabilizing factors must be recognized and effectively managed if the capitalist system is to be sustained and reproduced. However, because of its great complexity and hyper-dynamism, transparency and understanding is low. Bringing about substantial reform – without destabilizing the system – is also difficult and risky.[2] But not to initiate reform is also risky, as we argue later.
(7)Actors or groups of actors adversely affected by the operation or development of capitalism may socially articulate – in part, through communicating with one another -- their deprivations and disadvantages, e.g. with reference to norms and values about "rights," "distributive justice," "fairness," or even "efficiency and rationality." Some may mobilize to try to change the institutional set-up, or at least certain (for them) undesirable features of it. Such activities usually bring them into conflict with those having an interest in, or commitment to, the established institutional arrangements. For instance, beginning in the 19th century, labor movements challenged and struggled to change capitalism. This resulted in the politics of capitalism and significant welfare development in a number of countries.

In general, economic instability and substantial concentration of economic power and control over vast resources in the hands of relatively few have evoked in the history of modern capitalist development periodic attempts to establish regulatory institutions and policies designed

to limit such economic concentration.[3] These constraints are observable in the form of anti-trust laws, labor legislation, land-use regulation, regional development policies, pollution controls, etc.-- measures designed, at least in part, to prevent excessive negative consequences and the abuse of economic power, extreme inequality, and intense social conflicts. Typically, regulatory institutions are introduced after the fact, that is, after a period of substantial negative development and instability. The general pattern is that capitalist concentration of power and uneven development tend to evoke discontent and social movements – or the threat of such movements – to constrain or regulate negative features of development. This is particularly the case in societies with well-established democratic norms and institutions, a strong labor movement as well as other social agents concerned with the struggle for class, regional, environmental, and other interests. Such reactions (or even their potential) lead, under some conditions, to the establishment of institutional arrangements to regulate the concentration of economic power and negative development tendencies. Regulation in practice typically does not block or derail the uneven accumulation of economic wealth and power. However, it may constrain misuses and abuses of the power and their immediate economic as well as social and environmental effects.
(8) In most advanced countries (e.g., OECD countries), capitalism has been more or less successfully regulated and stabilized through the formation of elaborate regulatory frameworks, which are to a large extent state-organized or sanctioned but with substantial private interest involvement. Typically, institutional arrangements are established to deal with a variety of market failures and instabilities as well as to resolve or prevent major conflicts, and overcome major loss of confidence in or opposition to the system.

Class tensions and struggles are a persistent fact arising from the institutionalized differences in power, conflicting interests and commitments, and uneven development capabilities and tendencies. For instance, enterprise power relations translate into major decisions of owners/managers in, for instance, transforming or closing a workplace, determining the type and level of production and employment, introducing particular forms of technology and work organization, rationalizing production, determining directly and indirectly qualitative and quantitative aspects of the work environment, and allocating resources and profits. Workers and, if they exist their labor unions, may react in various ways to the subordination to capitalist power. Different forms of power struggle and conflict between owners/managers and workers over the conditions and terms of employment have been characteristic features of capitalist relations of production. These conflictive tendencies are not easily suppressed, although they may take a variety of forms. The modern state and its agencies attempt to regulate the conflictive relationships by establishing negotiation arrangements and norms to facilitate communication, negotiation, and agreement between capital and labor. Attempts are also made to establish and maintain a reasonable level of cooperation and productivity (for instance, with minimum levels of strikes, slowdowns, and other forms of labor-capital unrest) in the face of inherent conflict. The long and continuing formulation of factory and workplace acts and labor market legislation are well-known. Parallel to this has been the establishment and sanctioning of arrangements to negotiate and settle conflicts between capital and labor. Conciliation, mediation, and arbitration, and their normative and structural prerequisites have been outstanding mechanisms for reducing the intensity and violence of class conflict. Where these routines of relationship are established, group conflict loses its sting and becomes an institutionalized pattern of social life (Dahrendorf, 1957:20).

In general, the powerful tendencies in capitalism to generate conflict and socio-political instability explains the enormous importance of effective conflict resolution institutions and the need to continually reform institutional arrangements in order to accomplish an effectively functioning economy. There is, however, a difficult dilemma in trying to achieve a balance between optimal conditions for capitalist control over economic power and capital accumulation and expansion, on the one hand, and widespread societal support and legitimacy for capitalism, on the other hand. The promise of economic security is important. The welfare state, while costing substantially, is one of the major modern means of assuring widespread support and legitimacy for capitalist arrangements. But welfare has been periodically challenged and eroded, in part, because of the argument that it constrains or undermines capitalist development and, therefore, "long-term welfare."

In conclusion, modern societies have developed and continue to develop **revolutionary powers** – driven to a great extent by dynamic capitalism -- at the same time that they have bounded knowledge of these powers and their consequences. Unintended consequences abound: social as well as ecological systems are disturbed, stressed, and transformed. But new social agents and movements form and react to these conditions, developing new strategies and critical models and providing fresh challenges and opportunities for institutional innovation and transformation. Consequently, modern capitalist societies – characterized by their core arrangements as well as the many and diverse opponents to some or many aspects of capitalist development -- are involved not only in a global struggle but a largely uncontrolled experiment (or, more precisely, a multitude of experiments) . The capacity to monitor and to assess such experimentation remains severely limited. The current capacity to constrain and regulate global capitalism is very limited, and this increases the riskiness of the system. How then is the powerful class of global capitalists to be made responsible and accountable for their actions? What political forms and procedures might link the new politics suggested above to the global capitalist economy and, thereby, increase the likelihood of effective governance and regulation.

V. TOWARD NORMATIVE PRINCIPLES OF EPISTEMOLOGY, DEMOCRACY, AND POLICY IN DEALING WITH TECHNOLOGICAL RISK AND RISKY SYSTEMS

This article has stressed that many risks in modern society are discretionary. That is, they are dependent on human decisions: the design and operation of the socio-technical systems they construct. That is, collective decisions determine the initiative, and particular features of the initiative, of such developments as industrial development, or nuclear energy development, or advanced weapons development. In a certain sense, they are discretionary and "artificial" – including the quality of, and strength of commitment to, the safety guarantees surrounding a given technology. Since these systems are based on collective decisions, most individuals cannot decide whether or not they wants to take the risks -- rather the decisions appear as sources of potential, unintended negative consequences and even unavoidable dangers. Thus, they are similar to "natural catastrophes" for many individuals. But there are many risks in modern society, with respect to which individuals can influence the degree to which they are subject to them by changing their behavior (smoking, food selection, living area, type of job, etc.).

Our analyses suggest several principles which could prove useful in orienting public discussion and policy:

(1) Principle of Incompleteness – Bounded Knowledge and Limited Control

It is a truism of contemporary social science that all knowledge is socially constructed, but construction may take place in different ways and with varying consequences. The social and institutional context of knowledge production and testing differs substantially in science, a religious community, the business world, or political settings.

We create social systems for our own purposes, whether socio-technical systems, research institutes, enterprises, administrative units, democratic bodies, regulative agencies. Some of our creations are dangerous, or very risky constructions. Our knowledge of many of our creations is bounded, because the systems are all-too-complex and dynamic to be fully modeled and understandable. That is, the consequences of establishing and operating such constructions cannot be completely anticipated beforehand. Our limited knowledge capabilities concerns not only the operation (and especially interactions) of such systems but their social, economic, political, and environmental impacts. Examples are abundant: socio-technical systems such as nuclear power plants, information and communication systems, the New Genetics and its myriad of potential applications; weapon systems such as nuclear and biological weapons; the nation-state as a system of modern governance, welfare systems; capitalism as a system of production with its complex markets, enterprises, global outreach; “modernization”, and “globalization”, generally. They all are familiar to us, but they are not fully understood as operating systems even by experts, who typically know only a part, in some cases only a small part, of the systems.

Thus, our knowledge about many of our greatest creations and their consequences is incomplete (whether this is recognized and acknowledged, or not). One may recall the assessments of nuclear power as almost totally safe – with an extremely small, almost negligible, “probability” of a nuclear accident. Experience taught us otherwise. Because of the division of labor in science as well as all technical fields, systematic knowledge is fragmented. So are the respective communities of knowledge producers. Their languages and cognitive frames (with technical concepts, models, particular methods, etc.) are deeply divided. Our capacities are severely constrained in the mobilization and development of integrated knowledge to better understand and to manage complex systems. Ironically, the human species has never known so much about nature, human history, and social, political and economic systems. Nevertheless, we are unable to fully mobilize and integrate this knowledge in effective ways for understanding and dealing with many of the problems arising in connection with our greatest accomplishments. There is no lack of “information”. But knowledge requires a model to select what is relevant or important, and what is not, and ways to link and organize different pieces of information. Models are particular human constructions, which filter, organize, transform, and help interpret “information”. Furthermore, there is a major knowledge gap between scientific communities and the general public and their political leaders. This results in tensions, misunderstandings, and distortions in the interactions between scientific communities and policymakers, for instance in the process of applying expert knowledge to policy and regulative problems. (One may observe major contemporary efforts to overcome the gap, through the use of scientific advisors, offices of technology assessment serving executive and legislative bodies, science shops, focus groups, etc).

Knowledge fragmentation and knowledge gaps would simply be regrettable, a mere failing of modern universities and the communities of knowledge professionals, if there were not great dangers and risks connected with many of the systems we construct. Some of the dangers are obvious, as in the case of nuclear weapons (or nuclear energy), or the availability and utilization of dangerous chemicals or biological materials. Still, for many or most people, some of these dangers are not so apparent. They are identified and characterized by experts, for instance, the ozone and global warming developments. Others may not be apparent at all: for example, the modern nation-states (closely associated with many welfare developments but also a major factor in systematic violation of human rights, population cleansing, and genocide); or modern complex money systems; or globally expanding capitalism with its risks of economic, social, and political destabilization. Science and technical communities play a substantial role in conceptualizing and providing data and knowledge about such systems – at the same time, that unfortunately, social sciences and humanities remain handicapped in this respect.

In the face of potential dangers and risks, systematic attempts are directed at regulating these systems. Such efforts – even if politically feasible under some conditions – are rarely successful. This is not only the result of a lack of sufficient resources, weakness in the regulatory machinery, or the impact of “human factors”. It is also often the result of an inability to mobilize necessary knowledge and knowledge capacity. This is, in large part, due to the fragmentation of scientific and technical knowledge and of the knowledge gap between the sciences, on the one hand, and policymakers and the general public, on the other. Many recognize that something radical should be done in the face of increasingly dangerous and risky human constructions – not only the obvious technical creations but institutional ones such as those associated with global capitalism, or new forms of military intervention.

Bounded knowledge implies that control of any complex system will be limited. In part, this is because the models of the system are approximations of the actual behavior of the system. Thus the effects of any given control action may not be adequately predictable – the linear, non-interactive models can adequately predict in only a very limited domain the behavior of non-linear interactive systems. Indeed, the accuracy of prediction in that domain is in itself a source of danger and risk, since it leads to overconfidence in assessing the ability to control outside that domain, and a lack of sufficient attention to deviations from the model.

The limitations in knowledge and our ability to control complex systems arises not only from human frailty but from the nature of the systems themselves. Models of the systems are simplified, abstract representations of the system and are of necessity incomplete. They provide very limited capability to deal with emergent processes and with changes in the environment. At the same time, the complex systems that are at the heart of modern applications of science and technology nearly always generate emergent processes, and their social and natural environments are always changing.

There is a powerful tendency to develop decontextualized knowledge around complex systems. By decontextualized knowledge, we mean understandings of the system that are based on one perspective of the system, typically an abstract one, that does not or cannot take adequate account of other views that are based on particular, local situations or "hands-on" principles. The manager or engineer designing the system may have limited understanding of the practical problems faced by the construction worker or the system operator. The senior manager may see a project as a source of profit or loss while the worker on the line will see it as a job and/or as a source of professional accomplishment or as a context of solidarity or competition with fellow workers. Different actors approach the system with different perspectives (using different rule systems) and in essence are dealing with different socially constructed realities. Yet the system has both social and physical realities. Because of the decontextualization of knowledge, or more accurately, the lack of inter-contextual knowledge, physical and social realities are not fully understood anywhere in the system (this is a consequence then of "the tyranny of abstraction"). As a result, miscalculations, mistakes and failures are virtually inevitable.

Designing socio-technical systems that take account of the real limits to our understanding and control is a formidable challenge, but it is one that allows applied natural science and engineering and the social sciences to inform one another, and to facilitate the growth of each. In our view, the integration of actor-dynamics dynamics with cybernetic and engineering theories dealing with the complexity and stability of technological systems is essential for a proper understanding of modern socio-technical systems and the associated problems of effective regulation. This should imply a further operationalization and specification of both social rules and the rules built into complex systems, including modern technologies. It is certainly important to develop models in which questions about stability and complexity can be linked unambiguously to the character of the particular social rule systems constituting and governing complex systems. This is an important theoretical task with high practical relevance.

(2) Principle of Humility ("To err is human")

Most modern education generates – particularly under conditions of individual and group competition – reinforces hubris. At the same time our understanding of complex technologies and socio-technical systems and our ability to control them is limited. These limitations come not only from human frailty but from the nature of the systems themselves. Models of the systems are **simplified representations** of the system and are, therefore, incomplete. They provide limited capability to recognize and deal with emergent processes and with changes in the environment. At the same time, the complex, socio-technical systems that are at the heart of modern applications of technology nearly always generate emergent processes, and their social and natural environments are always changing.

All of this suggests that systems should be designed to be error tolerant, to enhance the ability to learn from experience, including trial and error, and to enhance contextualized knowledge. When complex, tightly coupled, high risk systems are necessary (or strongly motivated), the social context of those systems should be simple and consistent. The conflicts that result from mixed messages and incentives (e.g., build a safe system that maximizes profits) will make error and failure likely. The results can be catastrophic in some cases. Requiring that socio-technical systems that take into account the real limits on our understanding and control is a formidable challenge to parliaments and political leaders.

Social science research on technical controversy provides considerable insight into the dynamics of the controversy and the strategies and tactics of interested parties but does not provide the systematic analysis that integrates this research nor does it provide much useful guidance regarding technological choice. We hope that our discussion to this point has addressed the first problem. Here, in conclusion, we turn to the second problem, the implications of our framework for technological choice.

Perhaps the most important principle that follows from our analysis of technology is humility. There are many forces that move human understanding and control of complex technologies and even more complex socio-technical systems toward error and confusion. The forces that push toward accurate knowledge and towards effective control are real but not as strong as is often presumed. Thus, we believe it appropriate to be very humble in assessing what can and cannot be done, and what is and is not understood.

We believe it is appropriate to be cautious in several regards. Forecasts of demand, technological performance or other key aspects of the future that depend on models that in turn depend on what may be very limited or very decontextualized experience. At a minimum, any use of such forecasts should include estimates of uncertainty based not only on standard statistical procedures and expert judgment, but also on the historical record of forecast accuracy across a variety of applications.

Humility about assumptions is warranted. Analyses of technology often ignore the socio-technical system and the larger social system, or treat them only as disturbing sources of demand or obstruction, and reducing efficiency. Yet the larger social and socio-technical system constitute the environment for the technology. Ignoring them replaces analysis with assumptions, and in many cases those assumptions are often either naive or very politically biased. One positive step away from such narrow analyses can be seen with the increased emphasis on end-use analysis in energy analysis. Such analysis conceptualizes the problem of energy supply in terms of services provided by energy use, and thus allows an important role for increases in energy efficiency as well as for increases in energy supply. Carried a bit further, such humility about modelling and even conceptualizing whole systems in a mechanical way suggests that the critical problem in modelling and systems design are more political and ethical than technical. Efforts to develop approaches that allow for a more sophisticated understanding and elaboration of the political and ethical bases of technologies are critically important.

A final implication of humility comes in an understanding that the systems on which we depend and that are so influential in all aspects of our lives can never be perfectly designed from the outset, but must evolve, hopefully on the basis of greater knowledge and accumulated experience. Modern society should encourage structures that facilitate innovation, discussion and debate, learning and evolution rather than systems that "lock in" and stubbornly defined choices that while appropriate at one point in time by some criteria, may prove disastrous at other points in time and by other criteria. We need diversity in technology to allow selective forces at work, and active evaluations and impact analyses to guide those selective processes over which we have some control.

(3) The Development of Risk Consciousness and Prudentiality in an Open, Democratic Society.

``What characterizes modern society is not so much risk, natural as well as manufactured risks, but risk discourses, systems of risk assessment and calculation (in line with Weber's principle of rationalization), and a politics of risk assessments and decisions. The discussions and deliberations of risk entail the encounter of different perspectives and value orientations – especially in the context of democratic norms and procedures.[39] Not surprisingly, there has emerged a politics of risk engaging proponents and opponents, the latter questioning and challenging proponents of, for instance, nuclear power, the new genetics, genetically modified foods, etc. Earlier, opponents such as Luddites were viewed as irrational and devoid of vision and knowledge. In the contemporary world, opponents learn to use science and other expert knowledge in the struggles and negotiations with proponents of new projects and systems.

[39] Earlier, elites and dictators could conceptualize and judge matters in their own terms without taking into account the perspectives, concerns or sufferings of dominated or marginal groups.

The risk of models formulated by experts, for instance embodying the value or values they consider important, or that they attribute to society as important, is that they ignore or lead out of consideration values that may be important to others or that may be defined as important later. One obtains more simplicity, certainty in that there are fewer dilemmas or conflicts to resolve. For instance, an agent may pursue wealth or power (or an abstract ideal) without concern about the strategies or means used as in the case of actors with absolutist value orientations (this type of commitment is obviously not foreign to our economic and political culture). John Hall (Hall, 2000) has pointed out that the early Karl von Clausewitz (1780-1831), drawing on observations of the success of Napoleon, formulated the principle that the essence of state behavior is that of pursuing its ends without limit. After witnessing the collapse of Napoleon's ambitions, he came to distrust the unlimited quest for power and to propose a bounded or prudential orientation, thus imposing constraints on the pursuit of ends and also the construction of means, that is, to construct a more pluralistic and balanced value framework.

The perspective and analyses outlined in this paper suggest processes that will contribute to developing and normalizing prudentiality: (i) particular attention should be given to the limits of models of technologies and socio-technical systems, the inherent uncertainty and unpredictability of the systems we construct, manifested for example in the unanticipated consequences which are endemic to complex, dynamic systems (Burns et al, 2001). In other words, the hypothetical character of our knowledge, models, and beliefs must be emphasized. (ii) stress should be given to increasing public awareness and reflectivity on the technology systems proposed or created – this means opening up and engaging people in governance processes; (iii) also of great importance – especially in democratic societies – is to encourage and give value to multiple perspectives, pluralism, collective or public discussions and deliberations, and institutional arrangements to generate, reflect on, and judge **alternative** proposals.

Of course, the proposals above entails risks for elites and their advisors, namely **the risk of disagreement, opposition, and loss of a "contest**" The fear of, and even lack of tolerance for, this risk, especially, among elites must be overcome through the establishment of new norms and practices, which are basically egalitarian and democratic. Miller (1996:224) refers to this as a form of "anomie" – a normative based pluralism which accepts free thought, disagreement, and uncertainty. But there would also be a community of agreed norms and procedures – which we understand and accept even if we hold different philosophies, metaphysics and world views" (rather than a single coherent system). In his disposition, Miller rejects a "community of beliefs" and advocates a "community of norms and procedures" which accepts free thought, disagreement and uncertainty. Social integration and cohesion rests on diversity of a division of labor and the profound sentiment – the essence of religion – of sociability and attachments to one another and society. However, at the base, one still needs a community of belief or conviction in the ideal itself – which is one of the keystones of democratic culture.

Social sciences and humanities must be encouraged to contribute to methodological and epistemological discussions which highlight uncertainties and risks associated with technological and environmental developments; debunk expert claims to infallibility and absolute neutrality, and emphasize the need for norm formation and legal, ethical, and social regulation of complex systems (Kerr and Cunningham-Burley, 2000:298).[40] Many of the basic questions addressed here are not purely technocratic or economic issues, but entail questions of normative and institutional design and development. For such questions there are no true answers. One has to decide who should assume and exercise social responsibility and deal with particular issues and problem situations. In the context of redefining roles, the rights and obligations of participating actors, we emphasize the importance of establishing greater transparency and accountability for the far-reaching and diverse policy and "law-" making that goes on outside of the normal corridors of parliament and central government. In our view, the clock cannot be turned back to simpler more consistent arrangements for governance. Modern society is too complicated and far-too-dynamic to be overseen in any detail from a "center" (Burns, 1999; Andersen and Burns, 1992). At the same time, there have emerged a variety of highly flexible and adaptable forms of "self-governance" on all levels that make the old forms of regulation (e.g., detailed legal regulation) less applicable and less effective (particularly in the numerous specialized, technically demanding sectors of modern society).

A critical perspective is essential of course. At the same time, we need to engage in imagining and designing new institutional arrangements, ones that minimizes particularly dangerous risks; ones that generate products and make use of production processes compatible with environmental protection, sustainability, etc. Certainly, innovativeness, experimentation, and exploitation driven by "competitive systems" must be stringently constrained and regulated in highly risky areas of development. At the same time, we must develop new cultural orientations and rules reflecting bounded rationality and bounded control. As suggested above, even scientific communities and rational professions are capable of exaggerated self-confidence, self-deception, blindness and commitment to illusions and half-truths.

[40] One might also consider as an important principle of policy to support social science and humanities research on technological impacts. Here we have in mind taxing major (e.g., apparently revolutionary) developments for the purposes of systematic investigation and assessment. More specifically, major developments, such as information technology or new genetics, should be "taxed" (for example, a percentage of R&D investments initially and eventually a percentage of capital investments) in order to support research on the social impact of these developments. In a certain sense, this is already being done in the case of the Genome program with E.L.S.I. (Ethical, Legal, and Social Implications), which is funded on the basis of a certain percentage of the Genome program. This entails 2-5% of research budgets being devoted to consideration of social, legal, and ethical issues associated with genetics research and applications).

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[1] But even rich countries such as Japan may be trapped in such a vicious circle.

[2] And also, established power distribution. Ironically, while the unintended developments are often the consequences of the strategies and actions of dominant groups, they may, nonetheless, provide openings for some peripheral or subordinated agents to advance in position – or even to challenge the social order.

[3] While labor and other social movements are examples of sources of such social pressure, it is worth recalling that farmer and small business groups have also played prominent roles – and in some instances continue to play an influential role -- in the opposition to tendencies toward massive concentration of wealth and economic power in capitalist development. Although they may not challenge the principles of private property rights, they oppose those aspects of excessive power concentration, systems of credit, distribution, and government policymaking which appear to favor (or tolerate) economic domination.