CONSTRAINED CHOICE AND CONTINGENCY: MILITARY AND ECONOMIC COMPETITION AS THE MECHANISM FOR TECHNOLOGICAL DETERMINISM

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ABSTRACT

The study of technology is divided. There are scholars, found especially in sociology and history, who emphasize interpretive flexibility, agency and historical contingency. These I label 'mild-constructivists.' Other scholars, found especially in business, economics, military studies and macro-history, emphasize functional adaptation and "deterministic" trends. These I label 'sociotechnical adaptationists.' A theory of sociotechnical evolution can unify the insights of these seemingly contradictory approaches to technology.

Competitive processes constrain sociotechnical variation: the range of interpretations and choices available to an actor are constrained by the imperative to survive. Economic and military competition, in particular and in the long run, constrain an actor's decisions to those that promote, respectively, the profit or power of the encompassing 'social organism,' such as a firm or state.

Thomas Misa has noted that scholarship with large-scales of analysis tends to be technologically deterministic. At large scales of analysis, instances of economic and military competition are more common. I argue that economic and military competition is the mechanism that gives rise to emergent deterministic patterns. New technology "merely opens a door; it does not compel [us] to enter."[1] It is economic and military competition that shoves us through.

Military competition tends to operate over longer time scales and constrain economic and social competitive processes. Economic competition operates over middle time scales and constrains social competitive processes. These competitive forces "select" for economically and militarily functional sociotechnical

[1] White, Lynn. 1962. *Medieval Technology and Social Change*. Oxford: Oxford University Press, 28.

configurations. Thus, at larger scales of analysis the competitive processes giving rise to functionalist adaptation are more apparent.

A unified theory of sociotechnical evolution can reconcile the detailed micro-narratives of mild constructivism with the functionalist insights of the adaptationists. Almost all theories of technology are appropriate in their proper analytical context, defined by the character of variation (in particular, the degree of path dependency) and the kinds of competitive processes present.

There are, however, two approaches to technology which cannot be reconciled within a theory of sociotechnical evolution. They are radical social constructivism and naïve technological determinism. Scholars in the first group claim that there is unlimited interpretive flexibility, agency and contingency. Scholars from the latter group naively attribute agency to technology, failing to acknowledge the absence of a micro-theory for their claims.

The history of Japan's use of firearms provides an illustration of the utility of the sociotechnical evolution framework. The introduction of firearms into Japan, beginning in 1543, follows the adaptationist script: two firearms arrived with some Portuguese adventurers, were bought, reverse engineered, and soon produced and used in the hundreds and then thousands.

From the 1600s to 1853, though, Japan's use and development of firearms stagnated. Constructivist scholars could productively explore the social reasons for this 'reversion to the sword'. Their findings are bounded, though, by the conditions that characterized this period, namely: the absence of internal and external military competition.

In 1853 Commodore Perry's ultimatum ended this 250 year 'retrogression' by imposing a painful imperialist challenge. Japan could no longer maintain its isolation

without risking following the fate of China in the Opium Wars. Japan's ensuing industrialization and modernization poses a problem for both constructivist and adaptationist theories of technology. Japan eventually adopted superior Western military technologies, but not in the simple functionalist way that an adaptationist would expect. A satisfying history requires an appreciation for both the cultural and military context, and the ways that they interact.

BIOGRAPHICAL SKETCH

Allan Dafoe completed an undergraduate degree in Arts and Science, with a minor in Mathematics, at McMaster University in 2003. He pursued graduate work at Cornell University in the Department of Science & Technology Studies from 2003-2006. He will begin a Ph.D. program in Political Science at UC Berkeley in the Fall of 2006.

To Nana

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Tradition is not something constant but the product of a process of selection guided not by reason but by success. . . .

-Friedrich Hayek[2]

Introduction

Who—if anyone—controls technological change?

The most important, though often disguised, issue in the study of technology is the question of agency. Can individuals or groups modify their tools, and thus necessarily their systems of production, social relations, political systems, and world-view? Or, are we trapped within the unintended consequences of momentous technological systems that were built by yesterday's engineers? Or, are the majority of people obliged to use the technologies designed by the powerful to reinforce their rule? Or, does technology autonomously develop according to an "inner logic" that, for better or worse, determines society?

Prior to the 1970s, the view that technological change was an autonomous, "out of control," history-shaping process was, in many scholarly circles, well received. Since the 1980s, though, this view has been disparagingly labeled "technological determinism," and has been increasingly caricatured to the point where no sociologist or historian today would allow themselves to be so labeled. In the words of historian of technology Ronald Kline, "technological determinism" has become a "critics' term."[3] The pendulum of scholarly fashion has swung away from large-scale inferences about abstract technology-driven historical trends towards small-scale descriptive narratives that emphasize the agency of individuals and groups. While in other fields of social science this intellectual tension is regularly confronted under the

2 Hayek, Friedrich. 1985. *Law, Legislation, and Liberty, volume 3: The Political Order of a Free People*. Chicago: University of Chicago Press,166.
3 Kline, Ronald R. 2001. Technological Determinism. In *International Encyclopedia of the Social and Behavioral Sciences (3rd ed.)*, edited by N. J. Smelsa and P. B. Baltes. Amsterdam: Elsevier.

rubric of "structure vs. agency," or "determinism vs. voluntarism," or "inevitability vs. contingency," within the sociological and historical study of technology the debate has been won by the social constructivists and contextualists. And yet, to this day, in the neighboring disciplines of economics, geography, archaeology, and computer science, and in the discourse of business strategists and military planners, technologically deterministic claims are rampant.

Rather than dismiss the large body of scholarship—past and present—that finds technology to be a self-moving determinant of social change, this paper seeks to reconcile "deterministic" observations with the interpretivist insights and attention to micro-social action of constructivist approaches to technology. I introduce a conceptual category, "sociotechnical adaptationism," which encompasses those approaches to technology that explain change by appealing to the adaptiveness or functionality of technology. I argue that all sociotechnical adaptationist work rests on the critical mechanism of competition; economic and military competition constrain choice, historical contingency, and give rise to deterministic trends. I finally outline the beginnings of a theory of sociotechnical evolution which can reconcile the insights of constructivist and adaptationist scholarship by making explicit two key contextual parameters: 1) the path-dependency of variation in form, and 2) the character and intensity of selection processes (competition). I then look at the history of firearms in Japan because it represents one of the most dramatic examples of the social construction of technology, and, following 1853, one of the most radical cultural reversions concerning - and induced by - technology.

I propose that a theory of sociotechnical evolution, by emphasizing the processes of variation and selection, can reconcile interpretivist insights, micro-social action, and large scale technologically deterministic claims. To briefly summarize what such a theory argues: 1) All knowledge is imperfect, and socially and cognitively

mediated; 2) large scale historical patterns emerge from the actions of individuals and do not exist independently of individual actors; 3) technological change **enables** new sociotechnical configurations; 4) military or economic competition has been ubiquitous throughout history; 5) by definition, some configurations will out-compete others, and will proliferate through either conquest or imitation; 6) in a large population of competing actors, each individual is constrained (and driven) by the imperatives of successful competition. To summarize: in a competitive world, sources of sociotechnical variation (such as new technologies) will "drive history" by "opening the doors" that competing actors will be compelled to step through so as to survive. Competition constrains a group's feasible choice set to those few options that allow social survival, be it of the family, the tribe, the firm, or the state. Those who choose to not adapt (or are unable to adapt) become incorporated or destroyed by the dominant sociotechnical systems.

As the number of competing social entities approaches infinity, individual agency—the ability to shape the future—vanishes to nothing. Individual entities may only choose to innovate, imitate or be conquered; if they do not make the adaptive decision they will replaced by or incorporated into those entities that do make the adaptive decision. Historical change is determined by two sets of analytically separable factors, those that affect: 1) the variation in social forms and 2) the nature of the competitive environment. Technological change has been an important—though by no means the only—factor affecting the variation and selection of social forms. Other "social" factors have also been important, such as the creation of different ideologies and institutions. What is unimportant, in this picture of a world of many competing entities, is individual choice.

There are actually two debates about technological determinism: 1) whether technology is the most important (or only) factor determining historical change, and 2)

whether individual humans have agency: the ability to perturb historical trajectories.[4] In both debates, attention to competitive (or selectionist) processes provide a plausible mechanism for technologically deterministic claims, while at the same time situating their limits. First, whether technology is the "most important" factor is an empirical question, one that depends on the nature of variation and selection in different historical contexts (and scales of analysis). Second, as will be explained in the section below on sociotechnical evolution, selectionism points out that historical contingency (and therefore individual agency) is inversely related to the scale and intensity of inter-group competition.

For these reasons, the position I put forward in this paper should be called "sociotechnical evolutionism," with its more deterministic inferences properly called "sociotechnical adaptationism," rather than the ambiguous—bordering on meaningless—"technological determinism." Adaptationism believes that the characteristics of replicating entities (including social organisms like firms or states) are functional (also called adaptive or optimal) because functional traits tend to proliferate within competitive systems. Note that the terms 'functional', 'adaptive' and 'optimal' all imply a selection environment: functional *for what*, adaptive *for what*, optimal *for what*.

The question of whether "technical" or "social" factors are more important to historical change is not central to adaptationism, nor to the theoretical and political debates about agency and historical inevitability. Besides, most scholars of technology will allow a sufficiently expansive definition of technology, or technological systems, as to obviate the need for splitting hairs on whether the artifact, institution, or ideology is "more important." What matters to most

4 Elster, Jon. 1983. *Explaining Technical Change*. Cambridge, UK: Cambridge University Press, 32.

determinists/adaptationists and constructivists is whether our systems are "out of control," or whether we—humans—are in charge of our destiny, and how exactly that control is manifest.[5] To this question sociotechnical evolutionism offers an answer: we have the freedom to shape our destiny over those time horizons for which we are able to alter the relevant selection pressures; to the extent that we compete within a system over which we have no control, we are bound by "best practice."

Interestingly, this theoretical finding is more than academic. Never in history has humanity been more able to consciously design our global system: the possibility of choosing our destiny is within reach. Our world, however, remains divided into "self-help" states, or blocs, that acquire weapons and oil supplies in anticipation of future conflict. Furthermore, economic competition is intense and broad, constraining many government policies with the threat of capital flight and lost "competitiveness." Selectionist analyses point the way through confused political debates about effecting change: to guide social evolution one must, at the least, supervise military and economic competition.

In the real world, of course, neither ideal-type of extreme sociotechnical adaptationism or radical social constructivism is accurate: the world does not consist only of a large population of intensively competing actors, nor is competition absent all together.[6] During times of weak competition and with few competing entities[7]

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5 Winner, Langdon. 1977. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*. Cambridge, Massachusetts: MIT Press.

6 I will explain in detail how competition constrains interpretive flexibility and agency in the section on Sociotechnical Evolution.

[7] In this paper I focus almost exclusively on competition as the selectionist process; I do this because competition is a concept more easily grasped by readers who are unfamiliar with selectionist theory. To those who are familiar with selectionist theory, I acknowledge that selectionist processes need not be blatantly "competitive", such as with ecological selection where entities may be "competing to survive" with "nature." "Competition" is a useful metaphor, though, with which to introduce selectionist theory

there will be weaker selection for functional traits, more historical contingency, and the interpretivist critique will be central to understanding historical change: socially constructivist narratives will be the most compelling. In times of intense competition and many social entities, selection for adaptive traits will be strongest, historical contingency and agency will be constrained, the interpretivist critique will be only weakly relevant: sociotechnical adaptationist arguments will be the most compelling.

Furthermore, since there will be more actors, more opportunities for competitive interaction, weaker social ties and higher costs of collective action over larger scales[8] of analysis, adaptationist explanations are more appropriate—and consequently more prevalent—in macro-scholarship. Scholarship emphasizing interpretive flexibility and historical contingency are more prevalent and appropriate for studying processes over relatively smaller scales of analysis. Misa's observed correlation between macro-analysis and technological determinism can be explained by this relationship between the scale of analysis and the intensity and character of selection: as the scale of analysis increases, sociotechnical adaptationist explanations become more appropriate, the interpretivist critique less relevant, agency and contingency constrained, and sociotechnical variation induced through technological change becomes a central process in historical change. Technology does not simply drive history through autonomous linear progress, as naïve interpretations of technological determinism would suggest. Nuanced technologically deterministic claims can, however, be sustained through a sociotechnical adaptationist theory of history: technological change enables new sociotechnical possibilities, some of which

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since in most selectionist systems different entities compete for some resource, and especially in social systems, the selectionist environment consists largely of competition with other social organisms.

[8] Large temporal scales of analysis tend to involve large spatial scales of analysis because there are more opportunities for spatially distant factors to influence each other. Likewise, large spatial scales of analysis tend to involve large temporal scales of analysis, since distant entities tend to interact over larger scales of time.

out-compete their rivals and proliferate regardless of the wishes and interpretations of the conquered.

Theory

This paper seeks to reconcile two seemingly antithetical perspectives on technological change: "technological determinism"[9] and social constructivism. Both perspectives possess abundant supportive evidence, a large community of scholarly advocates, and a quickly appreciated prima facie plausibility. While some scholars situated in the extremes choose to converse only with those in their own camps, accusing the other camp of "technological determinism" or "relativist post-modernism," many scholars situate themselves uncomfortably between. Few scholars, however, have tried to unify these groups theoretically. Motivated by the epistemological prior that the tensions between two seemingly contradictory, yet independently compelling, explanations for the same phenomena ought to be resolved, I hope to offer an outline for a unified theory (sociotechnical evolutionism), built on a theoretical mechanism (variation and selection) which can explain how deterministic macro-historical dynamics could emerge from a constructivist micro-dynamic.

In the following sections I will survey, with particular reference to their theoretical implications and contradictions, first technological deterministic scholarship, and then social constructivist scholarship. After a brief epistemological interlude, I will then introduce a new category for a set of slightly deterministic theories: sociotechnical adaptationism. After laying out the theoretical landscape, I

9 Scare quotes to indicate that this nomenclature isn't balanced, "technological determinism" being a critic's term, social constructivism being the group's own self-designation.

will discuss what an encompassing unified theory—sociotechnical evolutionism—based on the analytical distinction of variation and selection, would look like. Finally, I discuss the history of firearms use and development in Japan as an illustrative example.

What is Technology?

One premise of this theoretical enterprise, as well as that underlying most studies of technology, is that 'technology' is a coherent concept that can be studied, and that insights from the study of a particular technology can be usefully generalized to other technologies. 'Technology,' though, may be an ill-founded concept, confusing more than clarifying, because of what it conflates and what it hides. If this is the case, then perhaps the deep divisions in the study of technology are not a cause for concern, since each disciplinary approach may be studying different entities which are confusingly conflated under the term 'technology'. I don't, however, believe this is the case, as I argue presently.

'Technology,' as a concept, emerged during the late 19th Century to fill a "semantic void, that is, a set of social circumstances for which no adequate concept was yet available."[10] 'Technology,' defined in 1909 as "the science or systematic knowledge of the industrial arts"[11] accomplished something which the terms 'mechanical,' 'practical' and 'industrial' arts could not. Firstly, 'technology' was able to transcend the "vulgarity" of the "idea of utility"[12], abstracting away from concrete connotations of dirty machines to the more refined and progressive pursuits of science

10 Marx, Leo. 1997. Technology: The Emergence of a Hazardous Concept. *Social Research* 64 (3).
11 Harris, W. T., and F. Sturges Allen, eds. 1909. *Webster's New International Dictionary of the English Language*. Springfield, Mass: G. & C. Merriam Co.
12 Kline. Technological Determinism;Knox, MacGregor, and Williamson Murray. 2001. *The Dynamics of Military Revolution: 1300-2050*. Cambridge: Cambridge University Press;Marx. Technology: The Emergence of a Hazardous Concept.

and business. Secondly, machines were increasingly embedded in large systems (such as the railroad) which involved extensive infrastructures and new forms of social interaction, training, financing, and legislation. 'Technology' came to encompass entire technological systems. And yet despite the word's vastness, abstractness and vagueness, 'technology' also continues to imply specific artifacts, like an automobile or transistor. 'Technology,' then, is a term referring to large systems composed of social, political, economic and mechanical elements, and yet at the same time the term focuses on specific mechanical elements: technical artifacts.

Leo Marx sees this dual meaning of technology as a source of conceptual danger. On the one hand, 'technology' in the abstract has grown so vague as to interpenetrate with almost all of 'society,' and yet we still speak about 'technology' as if it is a discrete thing. Thus, to ask about the "'impact' of a major technology like the automobile upon society makes little more sense, by now, than to speak of the impact of the bone structure on the human body."[13] 'Technology,' by putting our conceptual focus on the artifact and yet connoting the entire system, leads people to exaggerate the causal force of artifacts, rather than the social, political and economic relations that also constitute and shape these systems. This semantic confusion has led many people to treat 'technology' as if it were the:

> . . . causative factor-if not the chief causal factor-in every conceivable development of modernity.… ['Technology'] serves as a surrogate agent, as well as a mask, for the human actors actually responsible for the developments in question.… Because of its peculiar susceptibility to reification, to being endowed with the magical power of an autonomous entity, technology is a major contributant to that gathering sense, at the close of the millennium, of political impotence. By attributing autonomy and agency to technology, we make ourselves vulnerable to the feeling that our collective life in society is uncontrollable.[14]

13 Marx. Technology: The Emergence of a Hazardous Concept.
14 Ibid.

Leo Marx does not make specific recommendations concerning the use of 'technology.' A possible alternative, of which it seems reasonable to infer that Marx would approve, would be to avoid using the word 'technology' and replace it with two words for the two meanings. 'Artifact' can stand in the abstract for all useful material 'technologies': machines, devices, tools. 'Technological system,' or perhaps even better 'sociotechnical system,' can refer to the vast, hard-to-delineate systems. I will adopt this usage, where possible, because it does clarify much discussion.

However, even after the introduction of these two clarifying nouns, there remains a semantic need for 'technology'. We can see this in one present-day definition of technology as "a manner of accomplishing a task, especially using technical processes, methods, or knowledge."[15] 'Technology,' in this definition, is a term which denotes the set of all artifacts, practices and institutions that serve (or once served) as an intended means to some human designated end. For example, when we speak of the 'technology of education,' we mean something more than simply the artifacts used in education, and something different from the educational system itself.

The technology of education refers to all the computers, books and blackboards (artifacts), lesson plans, seating arrangements, grading and salary incentive structures (techniques), and the knowledge base and research of educational psychology and the subject matter that is being taught (knowledge base and its production). The expressions 'the educational system' or 'the sociotechnical system for education' refer to all of this and more. The 'technology of education,' however, refers to all those things within the 'educational system' that are (intended to be) functional, as well as putting emphasis on their (intended) functionality. The term 'technology' is both a reference to (functional) artifacts, techniques, knowledge

15 "Technology." Merriam-Webster Online. 2005 [accessed January 10th, 2005]. Available from www.m-w.com.

institutions and sociotechnical systems, but also an emphasis on their functionality, rather than their materiality. 'Technology,' then, is all those things that are technological or functional, as well as an analytical lens (emphasizing functionality) through which to see those things.

For this reason, I believe that though 'technology' as a category is indeterminate and does suffer from Leo Marx's critique, as an *analytical lens* it allows us to focus on functional aspects of the sociotechnical world. 'Technology studies' is the academic domain which studies (intended to be) functional artifacts, practices, knowledge and systems, as well as the meaning of functionality itself.

Like the three metaphorical pillars for the social sciences, 'economy,' 'society' and 'polity,' 'technology' as an abstract concept is inseparable from the totality of social reality. It is equally as impossible to point to some component of our social world that is not technological, as to something which is not social, economical or political. These terms, at their most abstract, each refer to the entire social reality. Yet they are not synonyms. Each term, or abstract lens, emphasizes different elements and relationships of this social reality. A computer is a different entity when seen through a technological, social, economic or political lens. 'Technology,' thus, is all those things that are functional, as well as a concept that emphasizes the functional elements of various things. The study of technology, then, is an analytical enterprise which focuses on the functional dimension of social reality.

In this document, then, I will use the (referential) synonyms for 'technology' when appropriate (such as tool, artifact, machine, technique, institution, ideology, system, etc.). I will, however, maintain the (conceptual) use of 'technology' to refer to and *emphasize the functionality of* artifacts, practices, knowledge or systems.

Technological Determinism

Merritt Roe Smith summarizes "hard technological determinism" as the belief that "technological development [is] an autonomous force, completely independent of social constraints"; human "agency (the power to effect change)"[16] is limited such that "changes in technology exert a greater influence on societies and their processes than any other factor."[17] Ronald Kline shares Smith's formulation of technological determinism: 1) technology develops according to an "inner logic independent of social influence"[18] and 2) "technological change determines social change in a prescribed manner."[19] Bruce Bimber, in trying to bring clarity to the discussion, radically defines "nomological" technological determinism as the claim that "there is only one possible future course of social change [that] 'would be the same no matter what people thought or desired'… History is predetermined by scientific laws that are sequentially discovered by people … which produce technology."[20] Given this extreme interpretation, it is not surprising that Bimber finds "technological determinism [to be a] rather unlikely account"[21] of historical change. The question of technological determinism is a multi-dimensional issue, concerning which the above critics have selected and conflated the most extreme positions on each intellectual axis for its definition. It is thus unsurprising to find that no scholar of technology would or does self-identify as a technological determinist. Ronald Kline has aptly identified this intellectual category as a "critics' term"[22] and suggested abandoning its use.[23] Its

16 Smith, Merritt Roe, ed. 1987. *Military Enterprise and Technological Change: Perspectives on the American Experience*. Cambridge, MA: MIT Press, xii.
17 Smith, Merritt Roe, and Leo Marx, eds. 1994. *Does Technology Drive History? The Dilemma of Technological Determinism.* Cambridge, MA: MIT Press, 2.
18 Kline. Technological Determinism.
19 Ibid.
20 Miller, Richard. 1984. *Analyzing Marx*. Princeton: Princeton University Press, 183, quoted in Bimber, Bruce. 1994. Three Faces of Technological Determinism. In *Does Technology Drive History?* edited by M. R. Smith and L. Marx. Cambridge, MA: MIT Press, 84.
21 Bimber. Three Faces of Technological Determinism, 99.
22 Kline. Technological Determinism.

imprecise and dismissive meaning serves more to delimit the boundaries of "acceptable" scholarship than to foster productive intellectual exchange.

If we understand "technological determinism" more charitably, though, as the claim that 1) there is some broad sequence and tempo of scientific and technical advance that 2) profoundly shapes historical change, and 3) is not entirely controlled by social choice,[24] then "technological determinism" has had a respectable scholarly history and present. In the absence of a more favorable label, throughout this paper I will use "technological determinism" to refer to those scholars who emphasize, to varying degrees, the above three related claims. If scholarly debate manages to avoid Bimber's strawman caricature of "technological determinism" in the future and adopts a moderate version of Roe Smith or Kline's definition, such as the one I outlined at the beginning of this paragraph, then a potent unified theoretical enterprise may be constructed, the first outlines of which I hope to develop in this paper in an integrated theory of sociotechnical evolution.

The above definitions of technological determinism collapse into two, often intertwining, intellectual questions: 1) Is technological change out of control, and 2) how important are "technical" factors in shaping historical change? While the first question—the question of agency—is what motivated both the determinists and their constructivist critics, the issue of technological determinism is often misleadingly framed in terms of the second question.

Following Thomas Hughes[25], I intend to distinguish these two overlapping meanings by referring to the claim that our sociotechnical system is largely out-of-

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23 Dafoe, A. Personal Conversation with Ronald Kline, 2005.
24 This formulation is borrowed from Robert Heilbroner, found in: Heilbroner, Robert. 1967. Do Machines Make History? *Technology and Culture* 8.
25 Hughes uses "technical" to refer to physical artifacts and software, and "technology" to refer to sociotechnical systems. Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*, 102.

control as *technological determinism*, and the more ambitious claim that *technical* factors are the most important determinants of historical change as *technical determinism*. Technical determinists are obviously also technological determinists, since if technical factors are the most important historical determinants then technical factors are more important than other factors, such as political systems, beliefs, or values, which might control historical change.

While technological determinists do tend to see technical trends as underlying or embodying the out-of-control forces facing humanity, few are interested in arguing over whether technical, economic or social factors are more causally determinative (sometimes called, respectively, technical, economic or social determinism). Most technological determinists would in fact argue that the process or trends that they describe also involve economic, political, social and psychological phenomena. Rather, the important point for technological determinists is that these processes are out-of-control, spreading a rationalizing logic that is largely, if not completely, independent of human will. Lewis Mumford perhaps expressed best the irrelevance of the technical/social distinction through his characterization of the deterministic process: "The Machine, by which I mean all the agencies of order, regularity, and efficiency, whether social or technical…."[26]

The claims of technological determinists, thus, should be read in the light of the question of agency. They argue, in short, that humans are forfeiting or losing control over their future, and that this loss of control has something to do with the spread of technological artifacts, systems, and ways of thinking and living. One strain of deterministic thought equated technological progress with endless social progress,[27]

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26 Mumford, Lewis. 1954. *In the Name of Sanity*. New York: Harcourt, Brace and Company, 106.
27 Marx, Leo. 2003 (1987). Does Improved Technology Mean Progress. In *Technology and the Future*, edited by A. H. Teich. Toronto, ON: Wadsworth.

and saw the rationalization of our tools and systems leading inexorably to a utopian world. These optimistic technological determinists, or techno-utopianists, were less concerned about agency: why worry about control when technological change is universally benevolent? Others warned about the perils of the ever-expanding, rationalizing, de-humanizing *technique*, mega-machine, or technological grid. To these pessimistic technological determinists, often just denoted as "technological determinists," who have been most attacked for vivifying the abstract noun "technology," the question of agency has necessarily always been paramount.

The Techno-Utopianists[28]

Techno-utopian thought—the belief that society could be improved socially, economically, and politically through the rational pursuit of scientific knowledge and technological progress—emerged during the Enlightenment and alongside the political revolutions in France, England, and America.[29] Since then, many intellectuals and social leaders from every political perspective—capitalist and communist, libertarian and statist, establishment and revolutionary—have proclaimed the benefits of the rational reorganization of our sociotechnical systems. The eloquent Senator Daniel Webster expressed the utopian view well in this 1847 speech heralding the dedication of a railroad:

> Truly this is almost a miraculous era. What is before us no one can say, what is upon us no one can hardly realize. The progress of the age has almost outstripped human belief; the future is known only to Omniscience.[30]

The new advertising amplified this creed by touting the social wonders that could be had from a judicious purchase of a particular brand of clothing, food,

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28 The following section benefits greatly from Merritt Roe Smith, in Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*
29 Marx. Does Improved Technology Mean Progress.
30 Quoted in Ibid., 6-7.

appliance, or automobile. Advertisers along with politicians exploited the appeal of the *technological fix*: rather than try to solve a problem by the painful old-fashioned methods of political conflict and moral introspection, the possibility of the technological fix allowed those who were responsible a costless solution. In some cases it worked.

The Year 2000. Herman Kahn and Norbert Wiener, exemplify well the optimistic and deterministic spirit of techno-utopianism in their book *The Year 2000*. In this 1967 text, Kahn and Wiener extrapolate various techno-economic trends, optimistically predicting a GNP for the United States for the year 2000 of between $7-23 trillion (1998 dollars), for which the published figure was over $9 billion. They also envisaged a range of likely discoveries, of which 30% came to pass.

Their corresponding predictions about how this newly grown wealth would be used and distributed, and its social consequences, however, were sorely misperceived. Kahn and Wiener envisioned dramatic social improvements: welfare services would provide a "high 'floor' under living standards. . . . The lower middle classes. . . would enjoy a greatly reduced work week. . . ."[31]

Kahn and Wiener's work exemplifies a number of facets of techno-utopian thought. First, Kahn and Wiener claimed to predict the future (at least in terms of GNP, fairly accurately) half a century distant based on technological and economic trends which they believed would persist. As such they believed that technological and economic change follows a benevolent "internal logic," one that is presumably endorsed by society. Like most determinists, they did not provide insight into the mechanism by which these trends perpetuate themselves, and thus into the possibility

31 Kahn, H. and A. J. Wiener (1967). The Year 2000 - A Framework for Speculation on the Next Thirty-Three Years. New York, MacMillan Company.

for social control were these trends to be no longer acceptable. Second, Kahn and Wiener exemplified the establishment belief that techno-economic progress is sufficient for social progress, and that political issues of representation, redistribution and environmental conservation need not be salient.

Technocratic Concept of Progress

Leo Marx characterizes the kind of argument espoused by Kahn and Wiener, and 120 years earlier by Webster, as the "technocratic concept of progress," wherein technological progress is conveniently regarded by the primary owners and beneficiaries of technology as the sufficient, if not only, means for broad social progress.[32] Langdon Winner summarizes the pattern:

> Since the earliest days of the Industrial Revolution, people have looked to the latest, most impressive technology to bring individual and collective redemption. The specific kinds of hardware linked to these fantasies have changed over the years: steam engine, railroad, telegraph, telephone, centrally generated electrical power, radio, television, nuclear power, the Apollo program, and space stations-all have inspired transcendental visions. But the basic conceit is always the same: new technology will bring universal wealth, enhanced freedom, revitalized politics, satisfying community, and personal fulfillment.[33]

Techno-Utopianism Today

Today, an extreme form of techno-utopianism has become commonplace, almost invisible because of its ubiquity. Omnipresent advertising spreads the gospel of technological fixes: friendship, romance, happiness, identity, and meaning can all be acquired through new possessions. Politicians wishfully promise technological solutions to our problems: nuclear attack can be averted through Ballistic Missile

32 Marx, Leo. 1987. Does Improved Technology Mean Progress. *Technology Review*;Marx. Does Improved Technology Mean Progress.
33 Winner, Langdon. 1997. Technology Today: Utopia or Dystopia? *Social Research* 64 (3);Zerbisias, Antonia. 2006. Urging People Not to Consume is a Tough Sell. *Toronto Star*, April 17th..

Defense, "[America's] addiction [to oil can be broken] through technology."[34] Mainstream economists proclaim the simple morality of their "science" that free trade and the free market are welfare improving, generally leaving out their theory's many assumptions.[35] Many businesses, ever in search of new sources of revenue, believe and espouse the endless promise of the new new thing to their shareholders. Respected scientists make claims, such as that by the authors of "Towards 2020 Science," that "a scientific revolution is just beginning [which may bring] a new wave of global social, technological and economic growth. The basis for this revolution is the emergence of new conceptual and technological tools from computer science."[36] This brief sampling of mainstream techno-utopianist thought could be indefinitely extended, at a rate roughly proportional to the daily output of "science and technology" sections from almost all news and business periodicals.

To techno-utopianists, who perceive technological progress as leading to social progress, the question of control was and is less pressing: even if they could radically perturb the system from its current trajectory, why would they? The techno-utopianists of the past and present, then, can be partly excused for failing to provide a fully specified mechanism for their claims, that is, a theory with micro-foundations. They have had less intellectual motive to precisely delineate the room for different kinds of human agency, since, most, if not all, of the actors in their story benefit from the predicted changes. However, to the extent that a sociotechnical forecaster envisioned possible negative consequences, the techno-utopianist intellectual exemption would not suffice. Techno-utopians, along with the most pessimistic

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34 Bush, George W. State of the Union. 2006 [accessed 05/16/2006]. Available from http://www.whitehouse.gov/stateoftheunion/2006/index.html.
35 For a more balanced economic appraisal of the risks attendant globalization, see Rodrik, Dani. 1997. *Has Globalization Gone Too Far?* Washington, DC: Institute for International Economics.
36 Emmott, Stephen, Stuart Rison, Serge Abiteboul, *et al.* 2005. Towards 2020 Science. Venice, 12, http://research.microsoft.com/towards2020science/background_overview.htm .

forecasters, share the unmet intellectual burden of fully specifying the mechanisms propelling change; in other words, all but the most naively optimistic forecasters share the determinists' theoretical shortcoming of failing to explain the constraints on individual and group agency.

The Technological Determinists

A writer need not be pessimistic to be a technological determinist, as the techno-utopians demonstrate. However, the technological determinists' most significant claim, that historical change is out-of-control, is most pronounced in the work of pessimistic sociotechnical forecasters, for whom either false consciousness or mass political impotence must exist. Thus, pessimistic sociotechnical forecasters face the technological determinist problematic most seriously: to specify the mechanisms driving sociotechnical change and constraining human agency. In the following pages I will survey the arguments of the most pessimistic technological determinists, that is those scholars most commonly denoted by the term "technological determinists." It should be kept in mind, though, that technologically deterministic scholarship also includes all the works of those who envision utopian, more moderate, or unpredictable social consequences arising from obdurate technical trends.

To the pessimistic technological determinists, the issues of control and collective consciousness are most pronounced. In order to explain the gradual crushing of humanity and nature beneath the spreading technological complex and technocratic ethos, the pessimists argued that the forces aligned behind technology were daunting, and could only be overcome by a collective awakening. Jean Jacques Ellul, while arguing that "technique… is artificial, autonomous, self-determining, and

independent of all human intervention" [37], nonetheless saw it as his purpose "to arouse the reader to an awareness of technological necessity and what it means[; to] call to the sleeper to awake."[38] Lewis Mumford warned that "man will become a passive, purposeless, machine conditioned animal" [39] unless we are able to throw "off the myth of the machine."[40] According to the pessimists, humanity is in serious trouble, and little short of a massive political, if not spiritual, awakening will save us.

Lewis Mumford famously adopted increasingly pessimistic and deterministic language towards the end of his life: "Like a drunken locomotive engineer on a streamlined train, plunging through the darkness at a hundred miles an hour, we have been going past the danger signals without realizing that our speed, which springs from our mechanical facility, only increased our danger and will make more fatal the crash."[41] Merritt Roe Smith summarizes Lewis Mumford as believing that

> 'our overmechanized culture' was rapidly moving toward a 'final totalitarian structure.' In the competition for world markets, industrial societies pressed hard to develop technological capacities that would give them an edge and, in the process, made the machine rather than the human condition the form against which all else was measured.[42]

Mumford writes that:

> Man will become a passive, purposeless, machine-conditioned animal whose proper functions, as technicians now interpret man's role, will either be fed into the machine or strictly limited and controlled for the benefit of de-personalized, collective organizations[…] There is no hope for mankind except by

37 Ellul, Jacques. 1962. Technological Order. *Technology and Culture* 3, 10, quoted in Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*, 30.
38 Ellul, Jacques. 1964. The Technological Society. Toronto, ON: Random House, Inc., 5, 19, quoted in Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*
39 Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*, 29.
40 Mumford, Lewis. 1970 (1964). The Pentagon of Power: The Myth of the Machine. New York: Harcourt Brace Jovanovich, Inc., 435.
41 Mumford, Lewis. 2000 (1952). *Art and Technics*. New York: Columbia University Press, 11-12.
42 Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*, 29.

> 'going with' [the plans of technocratic society] for accelerated technological progress, even though man's vital organs will all be cannibalized in order to prolong the megamachine's meaningless existence.[43]

But despite Mumford's deterministic language, like many other "determinists," Mumford leaves room for radical human intervention:

> "for those of us who have thrown off the myth of the machine, the next move is ours,"[44] for, "what the human mind has created, it can also destroy"[45] through "quiet acts of mental or physical withdrawal—in gestures of non-conformity, in abstentions, restrictions, inhibitions, which will liberate him from the domination of the pentagon of power."[46]

Jean Jacques Ellul used similarly deterministic language when describing how *la technique* is "artificial, autonomous, self-determining, and independent of all human intervention."[47] Ellul's writing has served as the basis for many later deterministic arguments and caricatures. While Ellul's claims remain underspecified, lacking plausible and detailed causal mechanisms, his prime purpose was to provoke humanity to awareness of their probable fate—for the "sleeper to awake." Unlike Mumford's simple political prescription for individual acts of passive resistance, Ellul's hoped for political awakening was but the first difficult step in regaining control of *la technique*.

Ronald Kline and Merritt Roe Smith have argued that Ellul and other technological critics who worry about technological unemployment and environmental catastrophes, in their efforts to mobilize political action, ironically paint a bleak deterministic picture that leaves little or no room for human agency.[48] Wiebe Bijker

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43 Mumford, The Myth of the Machine, vol. 1, Technics and Human Development (Harcourt Brace Jovanovich, 1966), 200, 435.
44 Ibid. 435.
45 Ibid. 420.
46 Mumford, Lewis. 1962. Technics and Civilization. New York: Harcourt, Brace & World, Inc., 188-194, quoted in Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*, 30.
47 Ellul. Technological Order. : 10.
48 Kline. Technological Determinism Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*

likewise sees technological determinism as "politically debilitating because [it] suggests that social and political interventions in the course of technology are impossible, thus making politicization of technology a futile endeavor."[49] While I agree that a theory of technology that leaves no room for human intervention—Bimber's extreme nomothetic technological determinism, and the more extreme or "hard" definitions posed by Roe Smith and Kline—would be politically disempowering, few, if any, "technological determinist" theories are actually that hopeless, including Ellul, Mumford, Winner, and Karl Marx. On the contrary, if our technological trajectory is strongly resistant to human intervention, then a theory of technology that significantly downplays this obduracy will itself be ineffective and debilitating, for it will induce unrealistic expectations and miscalibrated political strategies. Environmental activists do not paint a desperate picture so as to discourage political action, but to shatter the comforting illusions that easy reformist social and technological fixes will suffice. President Bush's recent State of the Nation promise to "break [America's] addiction [to oil] through technology"[50] avoided the political cost of confronting entrenched power-holders or the social and mental habits of American citizens, but will marginal subsidies for hydrogen fuel research really reduce the US's consumption of fossil fuels? Controlling autonomous technology requires radical social change, the determinists claim; radical social change can only be justified if our technological problems resist simple fixes. In the absence of compelling evidence that a politically distorted analysis will have a positive political effect, the duty of an analyst should be to not underestimate or overestimate, but to accurately assess the obduracy of social processes.

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49 Bijker, W. E. 2001b. Technology, Social Construction of. In *International Encyclopedia of Social and Behavioral Sciences*. Oxford, UK: Elsevier Science, Ltd, 15523.
50 Bush. *State of the Union*. [accessed].

Langdon Winner, one of the most eloquent proponents of technologically deterministic views, built upon Ellul's foundation with a more nuanced, yet still direly pessimistic, view of the historical trajectory of technological change. Langdon Winner's seminal work, "Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought"[51] centers the debate squarely, and properly, not on the question of whether technical or social factors are more important determinants of historical change, but on whether humans have control over their technologies and their future, and why it seems that sociotechnical systems posses a dynamism autonomous of their human components. Four of Winner's many contributions are particularly worthy of mention: the ideas of 1) the politics of artifacts, 2) the technological imperative, 3) unintended consequences, and 4) the socialization of allegiance to the technostructure.

51 Winner. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*

Do Artifacts Have Politics?[52] Langdon Winner argues that some technologies have a politics built into them by their creators. Robert Moses allegedly[53] built low bridges so as to keep buses and their poor passengers away from Jones Beach.[54] Napoleon ordered broad and linear Parisian roads to facilitate putting down riots. Gates and walls keep people out; keys (hard or digital) selectively allow some access.[55] While this point still inspires controversy amongst people unused to thinking about technology as a political structure, few scholars of technology would argue today that technologies can not be used for political purposes or do not have certain modes of action inscribed into them. Technical power is itself an expression of different degrees and kinds of power possessed by various social groups. Analytical attention to the social structure of various degrees and kinds of power adds an important theoretical nuance that many naïve determinists and constructivists ignore. The more tractable question, avoiding theoretical extremes, is not whether "people" have control over their destiny, but whether particular groups of people have or can acquire control. Thus, since historical decision making does not take place by all people at one time, but by particular people in particular circumstances, one should expect a theory of human agency to be sufficiently nuanced to account for the different circumstances facing socially differentiated actors.

52 Winner, Langdon. 1980. Do Artifacts Have Politics. *Daedalus* 109 (1).
53 For an empirical rebuttal to this claim, see Joerges, B. 1999. Do Politics Have Artefacts? *Social Studies of Science* 29 (3)
54 Winner, Langdon. 1986. *The Whale and the Reactor - A Search for Limits in an Age of High Technology*. Chicago: University of Chicago Press, 23.
55 Latour, Bruno. 2005. Where Are the Missing Masses? Sociology of a Door. Bruno Latour, 1992b [accessed 5-02-2005 2005]. Available from http://www.ensmp.fr/~latour/articles/article/050.html.

Technological Imperative. More controversially, Winner also argued that some kinds of technologies have an inherent political valence, often elicited through the necessity, or imperative, to adapt other sociotechnical systems to suit the new technology. Nuclear power, for example, requires an authoritarian organization structure to ensure against accidents, theft, and terrorism. Furthermore, nuclear power promotes central authority by forcing energy consumers to connect to the provider's electrical network, and hence conform to the provider's political and economic network. Nuclear power, in and of itself, does not compel these political reactions. However, "once nuclear power plants have been built … the kinds of reasoning that justify the adaptation of social life to technical requirements"[56] readily arise; the construction of nuclear power changes the relative costs of other sociotechnical choices, which will have political consequences. Lewis Mumford also advances the notion that certain technologies have a specific politics. Mumford argues that throughout history two kinds of technologies "have recurrently existed side by side: one authoritarian, the other democratic, the first system-centered, immensely powerful, but inherently unstable, the other man-centered, relatively weak, but resourceful and durable."[57]

56 Winner. *The Whale and the Reactor - A Search for Limits in an Age of High Technology*, 38.
57 Mumford, Lewis. 2003. Authoritarian and Democratic Technics. In *Controlling Technology*, edited by E. Katz, A. Light and W. Thompson. Amherst, NY: Prometheus Books, 422.

Unintended Consequences. Perhaps the least controversial claim made by the "determinists" is that technological change elicits unintended consequences: "technology always does more than we intend."[58] The machine gun and barbed wire unexpectedly gave rise to trench warfare.[59] The introduction of the automobile transformed American cities and culture. DARPA research on robust networked communication systems led to email and the world wide web.[60] The introduction of the snowmobile into the herding practices of the egalitarian Skolt Lapps of Finland delocalized and economically differentiated the community.[61] In the words of a National Security Council report on the near future, "most experts agree that the IT revolution represents the most significant global transformation since the Industrial Revolution . . . . [Though] we do not know to what extent technology will benefit, or further disadvantage … less developed countries…." Summarizing the possible consequences of the "IT revolution," and of the unintended consequences of technology more generally, this NSC report writes, "As technologies emerge, people will lack full awareness of their wider economic, environmental, cultural, legal, and moral impact…."[62]

To the extent that the unintended consequences of new technologies exceed their intended consequences, the development of technology exerts an unpredictable influence on society. In societies, such as our own, which prioritize technological innovation, the "random" buffeting of persistent unintended consequences should lead to unpredictable social changes:

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58 Winner. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*, p98.
59 Ellis, John. 1975. *The Social History of the Machine Gun*. Baltimore, Maryland: Johns Hopkins University Press
60 Abbate, Janet. 2000. *Inventing the Internet*, *Inside Technology*. Cambridge, MA: MIT Press
61 Pelto, Pertti J. 1973. The Snowmobile Revolution: Technology and Social Change in the Arctic. Menlo Park, Calif.: Cummings Pub. Co., 168.
62 Global Trends - 2015: A Dialogue about the Future. 2000. Washington: National Intelligence Council, 9, 14.

> A multiplicity of technologies, developed and applied under a very narrow range of considerations, act and interact in countless ways beyond the anticipations of any person or institution. Except in cases of extreme danger or disaster, there are almost no existing means for controlling or regulating the products of this chain of events. People still retain their logical position as users and controllers of technology. But in the broader context which transcends both 'use' and 'control', this logic is of little consolation. As the speed and extent of technological innovation increase, societies face the distinct possibility of going adrift in a vast sea of 'unintended consequences'.[63]

Were one to demonstrate that technological change has diminished the welfare of all (or most) related social groups, the technological determinist position would be confirmed, so long as we assume that people act in their own interest. Why would a set of social groups allow the welfare-reducing unintended consequences from their technological choices unless they did not have control over their own technological development? But if these unintended consequences consistently yield favored results, the determinists' claim becomes much harder to prove. A voluntarist—someone who believes that human will drives history—can easily argue that humans willingly choose to be set adrift on a "vast sea of unintended consequences," because the net benefits outweigh the costs. But while this techno-utopian voluntarist claim may be valid, it still fails to specify historical mechanisms that would illuminate the levers available to concerned citizens. Perhaps more condemningly, it is conveniently resonant with the interests of concentrated power-holders.

63 Winner. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*, 89.

The Magnificent Bribe: the Socialization of Allegiance to the Technostructure. Langdon Winner describes a 1969 report by the National Academy of Sciences[64] which makes the techno-utopian claim that "the advances of technology have yielded and still yield benefits that, on the whole, vastly outweigh all the injuries they have caused and continue to cause."[65] This quote, like much techno-utopian literature, implicitly argues that we have accepted technical innovation for its beneficial unintended consequences, and that we should continue to do so. This utopian view of technological change, which "has been a part of the tacit knowledge and most basic commitment of Western society for the last two hundred years[, believes that] technology is most productive when its ultimate range of results is neither foreseen nor controlled."[66] In support of this view one can easily point to numerous, seemingly beneficial, unintended inventions, such as the internet and penicillin. Furthermore, as compared to other societies, the last two hundred years have seen by far the greatest rise in human welfare in those societies characterized by this technological optimism and vigor,[67] measured in terms of life expectancy, access to material goods and knowledge, ease of transportation and communication, and in the proportion of the population that dies from war.[68] Perhaps Winner is correct to identify a tacit bargain between Western populations and the forces of technological development: so long as net welfare continues to increase, society willfully drifts on the pleasant waters of unforeseeable consequences.

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[64] Technology: Processes of Assessment and Choice. 1969. Washington, DC: National Academy of Sciences, Committee on Science and Astronautics, U.S. House of Representatives.
65 Ibid., 11.
66 Winner. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*, 98.
67 Pomeranz, Kenneth. 2000. *The Great Divergence: China, Europe, and the Making of the Modern World Economy*. Princeton, NJ: Princeton University Press, 31; Jones, Eric L. 1981. *The European Miracle*. Cambridge: Cambridge University Press, 3-5.
68 Keeley, L. H. 1996. *War Before Civilization - The Myth of the Peaceful Savage*. New York: Oxford University Press, 90.

Of course, this simple narrative of progress requires an implicit moral or utilitarian calculus whereby we can say that "net welfare" has increased. Economists, when pondering technological development or free trade, escape this paternalistic dead-end by envisioning a hypothetical compensation scheme to pay off the losers, a scheme that, alas, never quite takes place in the real world. In the absence of such a trans-temporal compensation scheme or unanimous vote, how does anyone, such as the National Academy of Sciences, decide that the increased freedoms and production possibilities of the internal combustion engine, for example, "vastly outweigh" the consequent dispersal of extended communities, suburban isolation, increased dependencies of non-drivers, growth of dictatorships in oil-rich regions, and the risk of climate change? By what calculus is the loss of certain cultural traditions by information and transportation technologies compensated by increasing economic and health indicators? Thus, the simplistic claim of the unqualified blessings of technological advance disguises the complexity of historical change; a serious questioning of our technological choices should not just ask if they have been "good" or "bad," but in what ways, to what extent, and for what and for whom have they been good or bad?

Serious interrogation of the total long run costs and benefits of technological change rarely take place in private firms, democratic fora, or academia; even short run technology assessment has lost resources and legitimacy with the closing of the Congressional Office of Technology Assessment. Given this lack of actual critical analysis, some more cynical social interpretations for the confidence of the techno-utopianists gain credence.

The techno-utopian promises of advertisers, business persons, politicians and others may proliferate so successfully because: a) many of the benefits of technological fixes are immediate and concentrated, while the costs are distant,

uncertain, and diffuse; b) technological fixes appeal to the greed, fears, and laziness of the audience, and c) they resonate with a techno-utopian ideology instilled into us through the technostructure.

John Kenneth Galbraith, in his analysis of "financial euphoria" where economic expectations clearly escape the bounds of common sense, explains a process of greed driven collective delusion, which may generalize to other cases:

> Some artifact or some development, seemingly new and desirable—tulips in Holland, gold in Louisiana, real estate in Florida, the superb economic designs of Ronald Reagan—captures the financial mind…. The price of the object of speculation goes up…. The speculation building on itself provides its own momentum [and produces a] vested interest in error…. Those involved with the speculation are experiencing an increase in wealth…. No one wishes to believe that this is fortuitous or undeserved; all wish to think that it is the result of their own superior insight or intuition. The very increase in values thus captures the thoughts and minds of those being rewarded. Speculation buys up, in a very practical way, the intelligence of those involved…. Strongly reinforcing the vested interest in euphoria is the condemnation that the reputable public and financial opinion directs at those who express doubt or dissent. It is said that they are unable, because of defective imagination or other mental inadequacy, to grasp the new and rewarding circumstances that sustain and secure the increase in values. Or their motivation is deeply suspect…. The euphoric episode is protected and sustained by the will of those who are involved, in order to justify the circumstances that are making them rich. And it is equally protected by the will to ignore, exorcise, or condemn those who express doubts.[69]

Further exacerbating this social departure from reality is the

> . . . specious association of money and intelligence…. There is a strong tendency to believe that the more money [an individual has] the more astute and penetrating his mental processes…. This view is then reinforced by the air of self-confidence and self-approval that is commonly assumed by the affluent.[70]

Could it be that this socio-psychological pattern for every periodic fit of "irrational financial exuberance," from Ponzi's schemes to Enron, "America's Most

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69 Galbraith, John Kenneth. 1993. *A Short History of Financial Euphoria*. New York: Penguin Books, 1-12.
70 Ibid., 13,14.

Innovative Company"[71], may also be an accurate description for the ideologies sustaining Western Civilization? Kurt Eichenwald explains how at Enron "the ever-rising bubble of market prices created a sense of invincibility among corporate executives, who read market delusions as proof of their own genius."[72] Arthur Brief, also speaking about the Enron case, agrees that social psychology has clearly demonstrated that "incentives and greed really blind."[73] Could these diagnoses also not be true, to a milder but more widespread extent, of modern capitalist societies—that most of us have been willing to believe a mild techno-utopianism because it justifies our short-term material gain?

Are we the short-term beneficiaries of an unsustainable process, in which we borrow from the future, miscount deductions in our capital stock, or otherwise create debt and call it income? Have we been euphorically counting reductions in our capital stock as income, such as through the consumption of fossil fuels and the rainforest? Have we been incurring a debt to the future, in terms of lost biodiversity, climate instability, and other long-term environmental processes, and called it "economic growth"?

Furthermore, besides the self-interested reasons for believing an ideology that justifies borrowing from the future and calling it income, perhaps our system is systemically biased towards the proliferation of consumerist techno-utopian ideologies. Advocates for simple living and reduced consumption, for example, are drowned out by the hundreds of billions of dollars spent on advertising, perhaps reflecting the Olsonian tendency of diffuse (environmental and social) interests to be overwhelmed by concentrated (business) interests. Have we moved women into the

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71 According to Fortune Magazine, for 7 years running, Enron was "America's Most Innovative Company":Q&A: The Enron Case. BBC News. 2006 [accessed 26/05/2006]. Available from http://news.bbc.co.uk/1/hi/business/3398913.stm.
72 Eichenwald, Kurt. 2006. In Enron Case, a Verdict on an Era. New York Times, May 26, 2006.
73 Ibid.

workforce, outsourced parenting to the television networks, eroded our social networks, accepted longer hours at more unstable and less fulfilling jobs, and counted it all as "growth" because the numbers are easier to add on the credit side of the ledger? In the rare case where an anti-consumption advocacy group, AdBusters, has been willing and able to pay for commercial airtime to spread their message, they have been roundly rejected by most networks, who see these "social marketing spots" as inimical to their "core business model" of selling effective advertising space.[74]

An example closer to home involves the 1997-1998 radical transformation of MIT's *Technology Review* in which the entire editorial staff was fired, motivated by "years of declining advertising revenue." The magazine transformed from a critical, policy oriented publication which published and sponsored the projects of those who feared an uncritical adoption of new technologies[75] to a publication whose new mandate, as characterized by former writer Winner and editor Marcus, respectively, as "boosterism" and "cheerleading for innovation." In the context of the above examples, in which anti-consumerist messages failed to attract or threatened advertising revenue, Winner's description of the construction of technological somnambulism, echoing other works by JK Galbraith, seems to ring true: "each group with any appreciable social power has gained auxiliary membership in the technostructure or has been put on its payroll."[76] Mumford concurs: "We are being asked to ratify … a magnificent bribe."[77] Perhaps techno-utopianism is so prevalent, then, not because it is accurate, but because it is a worldview well rewarded by advertisers, conglomerates reliant on advertising, businesses requiring unquestioning professional devotion, and ourselves, so as to justify our comfortable way of life.

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74 Zerbisias. Urging People Not to Consume is a Tough Sell., http://adbusters.org/metas/psycho/mediacarta/legal/inthenews.html
75 Langdon Winner wrote a regular column; Richard Sclove's Citizen's Panel was co-sponsored.
76 Winner. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*, 167.
77 Mumford. Authoritarian and Democratic Technics, 426.

Technological Trends

If unintended consequences are themselves a regular, and possibly expected, aspect of technical innovation, could they exhibit broad tendencies? While these unintended consequences could be effectively "random," depriving actors of agency without necessarily bringing great suffering or betterment, many technological determinists observe such long-term trends, be they utopian or dystopian.

Economist Robert Heilbroner, in his foundational article "Do Machines Make History?", expresses what many people commonly believe, that there is a broad sequence to technological progress:

> The steam mill follows the hand-mill not by chance but because it is the next 'stage' in a technical conquest of nature that follows one and only one grand avenue of advance… It is impossible to proceed to the age of the steam-mill until one has passed through the age of the hand-mill, and in turn one cannot move to the age of the hydroelectric plant before one has mastered the steam-mill, nor to the nuclear power age until one has lived through that of electricity.[78]

Heilbroner's grand avenue seems prima facie compelling: surely some technologies require the prior invention of other, more basal and simple technologies. Science writer Robert Wright points out likewise how, "archaeologists can't help but notice that, as a rule, the deeper you dig, the simpler the society whose remains you find."[79] At this point technological determinism makes connections with social evolutionism[80], seeing in history a tendency towards "increased hierarchical differentiation and …complexity"[81], increased "energy harnessed per capita [and]

78 Heilbroner. Do Machines Make History? : 336.
79 Wright, Robert. 2000. *Nonzero-The Logic of Human Destiny*. New York: Pantheon Books, 16.
80 The following quotes come largely from Carneiro, Robert L. 2003. *Evolutionism in Cultural Anthropology*. Boulder, Colarado: Westview Press
81 Adams, Robert McC. 2001. Complexity in Archaic States. *Journal of Anthropological Archaeology* 20:345

efficiency"[82], "toward increasing social and political complexity"[83], and "toward greater complexity."[84] In fact, there are abundant uncontroversial easily quantified trends, which are more robust at larger time and space scales, such as an increase in: population size, absolute and per capita GDP, speed of transportation and communication, life expectancy, education and access to knowledge, and the lethality of weapons, to name just a few. On more technical criteria the list can be extended in almost any direction conceivable: durability of materials, efficiency of engines, marginal productivity of labor, costs of storing and reproducing information, height of buildings. . . .[85] These trends need not extend monotonically, that is in one direction at all scales of analysis, for them to warrant analysis and explanation. Even the laws of physics, such as gravity, express themselves cleanly only in simple environments such as a vacuum, devoid of confounding influences such as wind. Obviously, any laws of or trends in history, if they exist, will coexist with some noise.

An eminent historian of technology has recently noted, despite the professional socialization against such deterministic claims, at least one such obvious technical trend. Historian of computing Paul Ceruzzi states that an "internal logic is at work"[86] in the evolution of some technologies. For example, over the past 40 years the "exponential growth of chip density has hardly deviated from its slope,"[87] as described by "Moore's Law." Ceruzzi infers from this evidence that historians of technology

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82 White, Leslie A. 1949. *The Science of Culture*. New York: Farrar, Straus and Company, 363, 368.
83 Fagan, Brian. 1999. *Archaeology, A Brief Introduction*. 7th ed. Upper Saddle River, N.J.: Prentice Hall, 234.
84 Trigger, Bruce. 1998. *Sociocultural Evolution*. Oxford: Blackwell Publishers, 1.
85 Some of these trends should be thought of in terms of the maximum levels extant at any given time, since a "mean" or "median" or any other statistic may be impossible to calculate. For example, while it makes little sense to talk about the mean "lethality of weapons," the maximum lethality of weapons is a much more tractable measure.
86 Ceruzzi, Paul. 2005. Moore's Law and Technological Determinism. *Technology and Culture* 46 (3), 593.
87 Ibid., 586.

should "step back from a social constructionist view of technology" and consider that, in at least some cases, "raw technological determinism is at work."[88]

The techno-utopians claim that these trends underwrite social progress. Many of the technological determinists who are not caught up in the financial inducements to cheerlead for innovation reasonably note that these technological trends have mixed and unpredictable consequences for humanity. Business "reengineering" guru Michael Hammer writes that the tendency towards increased social disruptions (or dynamism), whether for "boon or bane," is "the inevitable result of technological advances and global market change. The question that we must confront is not whether to accept [technology induced change] but what we make of it."[89] A National Intelligence Council futures forecast notes our ignorance of the near-term consequences of technology on the welfare of developing countries.[90] Joseph Strayer, summarizing the history of Western Europe during the Middle Ages, notes:

> If there is steady progress anywhere, it is in the field of technology, and yet this kind of progress seems to have little connection with the stability of society or with the degree to which a civilization satisfies those who participate in it.[91]

While there is no *a priori* reason why technology should not regress, since routines, knowledge, and inputs can certainly be lost, technological change does seem to be sufficiently "additive" and "cumulative" that old means of doing things tend to be superseded by more effective, powerful, and efficient means. Within the later section on Sociotechnical Evolution I will elaborate why technology seems to develop

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88 Ibid., 593.
89 Hammer, Michael. 1996. *Beyond Reengineering: How the Process-Centered Organization is Changing our Work and our Lives*. New York: Harper Business, 265, cited in Winner. Technology Today: Utopia or Dystopia?
90 Global Trends - 2015: A Dialogue about the Future. , 9, 14.
91 Strayer, Joseph R. 1955. *Western Europe in the Middle Ages*. New York: Appleton-Century-Crofts, 224.

"additively," so as to exhibit such long-term trends. Suffice it for now to acknowledge the abundance of evidence for these trends. Langdon Winner succinctly expresses the impression that there are long-term technological trends: "In the end, the best 'theory' for [technology in our world] might well be a series of aerial photographs showing the gradual expansion of the technological grid."[92]

The technological determinists are right to argue that technological change is a powerful historical force. They failed to provide, however, a plausible mechanism by which "technology" had gained such autonomy. The techno-utopians could be partly excused for this neglect because they could credibly say that humanity had unleashed the technological forces for their attendant prosperity. The non-utopian strains of technological determinism, however, needed to show **how** "technology" could so easily prod humanity down the plank. This intellectual failure rightly led to the "self-evident"[93] voluntarist/constructivist counter-argument: that a human, not "a row of machine tools," is "a compelling historical agent"[94], and that "human beings construct machines, not the reverse." [95]

Social Study of Technology

The study of technology has emerged from a divided disciplinary landscape, and it is thus not a surprise to find that it is spread among various research programs in different disciplines. Evolutionary and neo-classical economists, structural and

92 Winner. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*, 278.
93 Williams, Rosalind. 2002. *Retooling: A Historian Confronts Technological Change*. Cambridge, MA: MIT Press, 117.
94 Misa, Thomas J. 1988. How machines make history and how historians (and others) help them do so. *Science, Technology, and Human Values* 13:308-331 320.
95 Ibid.

constructivist sociologists, historians, philosophers and political theorists have each approached the study of technology from widely different perspectives. In this section I will survey some aspects of the social study of technology, with particular emphasis on social constructivist perspectives. I will emphasize particularly Sergio Sismondo's distinction between radical and mild social constructivism. [96]

Constructivism in Technology Studies

A study of technology in terms of functionality foregrounds a number of questions. For what is the technology (supposed to be) functional? How were those ends chosen (or imposed), and how are they changing? How has the functionality been created and maintained? How do technicians measure the technology's success at functioning?

Social constructivist scholarship responds to these questions in a way that doesn't take simplistic claims of technical efficacy, economic or military efficiency and historical causality at face value. Social constructivist scholarship looks beneath the apparently obvious functionality of a technology and asks how the (perceived) need for this technology arose in the first place, and how this artifact (among others) fulfilled this need. In other words, how were the means (technology) and the ends (desired functionality) constructed.

For example, a naïve economist might argue that a product emerges to fill a market niche and that the product will diffuse proportionally to the product's technical efficacy/relative cost. A social constructivist, on the other hand, will highlight the many points of contestation and active social shaping by key actors and groups. A firm doesn't just 'fill' a niche with a new product, but will often create the niche for its product to fill. Consumers do not judge products on some obvious linear objective

96 Sismondo, Sergio. 1993. Some Social Constructions. *Social Studies of Science* 23

scale, but instead interpret the product in different ways, again often helped by the producer. Furthermore, "consumers" are not a homogenous population, but will interpret and engage with products in distinctive, culturally contextual ways.

Social constructivist approaches to technology emerged partly in reaction to and as rejection of 'technological determinism'. As discussed above, 'technological determinism' refers to the belief that 1) there is some broad sequence of scientific and technical advance that 2) profoundly shapes historical change, and 3) is in some sense independent of social choice. In response to this view, social constructivist approaches to technology emphasize that any given technology 1) can have interpretive flexibility, such that its meaning is not obvious or technically inherent, and 2) contingently develops within the discourses and conflicts of various social groups. Therefore, a particular technology is not a static self-evident thing, but rather a "bundle of meanings"[97] that are contested by different groups.

Sergio Sismondo argues that "'social construction' … does not generally mean the same thing from one [S&TS] author to another," nor often "even within the same work." Some scholars, such as Karin Knorr-Cetina, speak as if "constructivism is a very specific research programme," while others, such as Pinch and Bijker, "call all recent sociology of scientific knowledge social constructivist."[98] Sismondo divides socially constructivist literature into two categories, which Trevor Pinch also adapts: radical and mild.[99] Mild constructivism includes those works that "display the social processes that lead to institutions, epistemologies and knowledge… [and have] helped to erase the positivist picture of science [and technology] as a purely rational activity,"

97 Bijker, W. E. 1997a. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change.* Cambridge, MA: MIT Press
98 Sismondo. Some Social Constructions.
99 Pinch, Trevor. 1995. The Social Construction of Technology: A review. In *Technological Change: Methods and Themes in the History of Technology*, edited by R. Fox. Amsterdam: Routledge (UK)

[100] while still leaving room, at least implicitly, for Berger and Luckmann's "*reality* (without scare quotes)…the real world, objective reality, or that which cannot be wished away."[101]

Radical constructivism (also sometimes called idealism or relativism) advocates that "representations routinely create their objects," and that "*nothing but* negotiation makes up knowledge."[102] Sismondo writes that "while many constructivists seem to want to buy into [the] radical claim that knowledge depends upon nothing but negotiation, their work tends not to lean on it in any important way, and often seems to contradict it."[103] Sismondo emphasizes that radical constructivism "has weak arguments supporting it and, contrary to the standard rhetoric, is [of little importance] to most of the actual work done."[104]

In 1987 *The Social Construction of Technological Systems*[105] was published, a foundational text for constructivist approaches to technology. In it were represented the three main theoretical approaches that are commonly labeled socially constructivist: the social construction of technology (SCOT), the technological systems model, and actor-network theory (ANT). SCOT is nominally radically constructivist, though, as Sismondo points out, "most of the actual work done" is mild constructivist. Hughes' systems model, in particular his concept of technological momentum, should be coded as mild constructivism, with sufficient path dependency to make it "somewhere between the poles of technological determinism and social constructivism."[106] ANT reflexively defies categorization.

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100 Sismondo. Some Social Constructions. , 526.
101 Ibid., 518.
102 (italics mine) Ibid., 541.
103 Ibid., 541.
104 Ibid., 515.
105 Bijker, W. E., Thomas P. Hughes, and Trevor Pinch, eds. 2001 (1987). *The Social Construction of Technological Systems*. Cambridge, Mass: MIT Press
106 Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*, 101.

SCOT: the Social Construction of Technology

The Social Construction of Technology (SCOT) rests on the idea that there is "interpretive flexibility" surrounding any given artifact, apparent in the way that different "relevant social groups" attribute different meanings to the same object. This shows that "neither an artifact's identity nor its technical 'working or 'nonworking' is an intrinsic property of the artifact but is subject to social variables."[107] The next stage of the analysis is to map the changing degrees of "stability" of meaning that the artifact possesses, as various "closure mechanisms" are enacted. In the classic bicycle example given by Pinch and Bijker, the highwheeled Ordinary was "at least two vastly different artifacts: the Unsafe Machine for women and older men, and the Macho Machine for 'young men of means and nerve'." In this case, two different groups had very different ideas about what the function of a bicycle should be, and thus different ideas about how to improve it, which consequently led to divergent bicycle models (the safe Singer Extraordinary and the faster, more dangerous Rudge Ordinary).

The above classic example, as Sismondo has argued, does not live up to the radical theoretical rhetoric that accompanies it. The two relevant social groups of "macho men" and "women and old men" seem to agree on each other's interpretation of the *content* or *technical workability* of the artifact. These social groups would both agree about the intrinsic properties of the highwheeled Ordinary: it is high off the ground and fast, and hence dangerous on both counts. What is socially constructed, or socially derived, is their *preferences* for a certain kind of bike. The macho men prefer dangerous and daring bicycles, and thus interpret the *high and fast* Ordinary as a "Macho Machine." The women and old men prefer safe bicycles, and thus interpret

107 Bijker, W. E. 2001a. Sociohistorical Technology Studies. In *Handbook of Science and Technology Studies*, edited by S. Jasanoff, G. E. Markle, J. C. Petersen and T. Pinch. Thousand Oaks, California: Sage Publications, 252.

the *high and fast* Ordinary as "Unsafe." Social construction operates not on the technical qualities of the artifact, but on the relationship between those properties and the desired functionality of the relevant social groups.

Radical constructivism is not theoretically compatible with most other theories of technology. Mild constructivism, on the other hand, is "fully compatible with either empiricism or realism,"[108] and is consequently amenable to theoretical cross fertilization with other realist fields. Within the section on Sociotechnical Evolution I will attempt to outline a meta-theoretical structure within which different realist approaches to technology can be unified. This cross fertilization, however, is unlikely to take place if mild constructivist scholarship persists in advocating for untenable radical constructivist claims.

Bijker states that the "truth of scientific statements and the technical working of machines are not derived from nature but are constituted in social processes"[109]. Likewise, Pinch argues that work "carried out in the recent sociology of science has shown how the very entities of modern physics are socially constructed. It is such approaches that SCOT attempts to emulate."[110] According to Pinch, it is not enough to say that "technology is embedded in human affairs." Radical constructivism shows how "an artifact, including its workability, can be subject to radically different interpretations."[111] Do Bijker and Pinch intend to imply that the technical workability of machines is solely a product of social processes, and has no relationship to the inherent technical qualities of the artifact? This semantic ambiguity is worth noting. To say that "X is socially constructed/constituted" is not, strictly speaking, to say that

108 Sismondo. Some Social Constructions.
109 Bijker. Technology, Social Construction of
110 Pinch. The Social Construction of Technology: A review
111 Ibid.

it is only socially constituted, and can't also be materially constituted. But it does seem to imply it.

In other writings, Bijker seems to retreat from his (self-acknowledged) radical constructivism by discouraging "social reductionism" and encouraging "symmetrical" attention to "technical factors."[112] Furthermore, the actual research done by Pinch and Bijker does not rely on, nor support, these radical claims. This issue arises as early as in the bicycle case study, where Pinch and Bijker argue that the differences of interpretation are:

> 'radical' because the *content* of the artifact seems to be involved. It is something more than what Mulkay rightly claims to be rather easy [or mild]—'to show that the social meaning of television varies with and depends upon the social context in which it is employed… It is much more difficult to show [that] what is to count as a 'working television set' is similarly context-dependent in any significant respect.[113]

But have Pinch and Bijker truly shown that the *content* of the bicycle is interpreted in different ways, rather than just the meaning of technically determined content? Both social groups would agree that the highwheeled Ordinary is technically high and fast. They would just disagree over whether these are desirable traits in a bicycle.

Perhaps the debate reduces to semantics. 'Workability' is a concept that relates the technical properties of the artifact to the preferences (or desired end or functionality) of the user. To show that 'workability' is dependent on context is not to show that the technical properties of the artifact is dependent on context. An example is Mulkay's hard-case for radical constructivism. The 'workability' of a television set may mean different things for different people, such as whether it displays the proper

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112 Bijker. Sociohistorical Technology Studies, 251.

113 Pinch, Trevor, and Wiebe E. Bijker. 1987. The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. In *The Social Construction of Technological Systems*, edited by W. E. Bijker, T. P. Hughes and T. Pinch. Cambridge, Massachusetts: MIT Press, 41-42.

programs, signals wealth and status, or even serves as a horizontal surface for resting drinks. But the technical properties underlying these different desired functions are not interpretively flexible. The television either turns on or it doesn't. The television is either the expensive brand or it is not.[114] The television's horizontal surface holds drinks or it doesn't.[115] In this case where preferences or desired functionality are uniform, the artifact and its workability, as Mulkay argues, does not seem interpretively flexible. Thus, even in Pinch and Bijker's primary case study for radical constructivism they did not achieve their radical aims.

A more generous illustration of the radical constructivist epistemological/ontological claim of interpretive flexibility comes from the prelaunch decision of whether the Challenger mission should go ahead, despite cold weather. Though possessing the same set of data, critics argued that the "O-ring test data could not be extrapolated to the low temperatures," whereas NASA managers believed that the extrapolation was valid. In this case, the two groups ostensibly disagreed over the technical safety of the shuttle launch, allegedly illustrating how technical issues are interpretively flexible and thus find closure through (and only through) social negotiation.[116] In this example, too, there are a number of theoretical holes that drain the radical force from the idealist constructivist claim. A mild, yet cynical, constructivist could see this narrative not so much as an example of how technical properties are completely flexible in their interpretations and thus strictly socially determined, but of how social actors use partially ambiguous data to manipulate

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114 What the brand signals (or means), on the other hand, is socially constructed, just as what a fast dangerous bicycle means is not fixed. But that the bicycle is fast and dangerous, that the television is brand X, finds ready agreement.

115 In each of these cases one could argue that there are degrees of workability, a television may turn on but yield a scrambled signal, the television may hold some kinds of glasses with a less than 100% reliability. These "grey" cases do not undermine the general argument that most people will be able to agree on whether the technology is operational in the way that they desire.

116 Pinch. The Social Construction of Technology: A review

underdetermined technical arguments towards their preferred outcome. The NASA managers had an incentive to meet the shuttle launch deadline which gave them reason to 'err' on the side of risk. If anything, this example illustrates not how technical properties are strictly socially determined, but of how partially ambiguous technical properties will be interpreted to suit the interests of the particular social group. It is a cynical view of the world, but not relativist.

Social constructivism can tell the strongest stories during times of technical disputes, often early in a technology's development. This is a case of where the exception illustrates the rule: constructivist stories are compelling when the technical properties of an artifact are still underdetermined. As technologies "age" they lose interpretive flexibility not just because they gain inertia (a la Hughes) or undergo social closure mechanisms, but also because more is known about the technical possibilities of a given technology. In Pinch and Bijker's classic paper, the technical usefulness of the air tire was originally disputed and flexibly interpreted. After a series of competitive public races, though, bicycles with air tires repeatedly demonstrated themselves to be the fastest. In this case, the technical properties of the air tire lost its interpretive flexibility as it lost its underdetermination: through repeated public observation of the technical workings of the artifact (rather than exclusively through social negotiation). The materiality of artifacts can only be 'wished away' where technical matters remain largely underdetermined or the consequences of inaccurate technical models are insignificant.

These substantial flaws in radical constructivism, however, are irrelevant to most of the work done under the SCOT and constructivist flag, since radical constructivism is "the least important of these different constructivisms to most of the

actual work done in [S&TS]."[117] As an example of mild constructivism, SCOT has been very fruitful.

The core strength of SCOT is the attention it pays to the non-linear evolution of technologies. Preferences are not uniform, nor are they simple and given. The meaning of a technology will differ among groups, and the final shape of the technology will reflect the complex and contingent social contest among these groups. Sometimes a technology will split and specialize into a number of new technologies in order to satisfy the various desired functions of different groups. Other times, one group is able to impose its will, and hence its meaning, onto other groups.

In more recent work, SCOT has been able to address issues that were originally under-theorized. Recent work has corrected the initial emphasis on construction at the design stage by showing how users are much more than passive consumers, but themselves often 'hack' the technical workings of a technology and inspire future design innovations. Users, that is, contest and co-construct the perceived purpose of the technology (its intended function).[118]

A good example of the agency of users in shaping technology comes from Kline and Pinch's account of some uses to which the automobile was put in rural U.S.A. Many rural users, instead of passively accepting the automobile as a necessary improvement on transportation technology, passionately opposed it, calling it the "red devil" and the "devil wagon." Some groups went further in their resistance by sabotaging roads with ditches and sharp metal objects, and attacking motorists. Furthermore, even when users had purchased an automobile their interpretation of its uses were complex. Far from simply being a mode of transportation, some rural users

117 Sismondo. Some Social Constructions.
118 Oudshoorn, Nelly, and Trevor Pinch. 2003. *How Users Matter: The Co-Construction of Users and Technology*. Boston: MIT Press

used the automobile as a source of power for their various machines (such as corn shellers, grinders, saws, pumps, and washing machines).[119]

In other recent work, Bijker has improved SCOT by filling the theoretical hole linking "the wider society in which the technology is immersed and its development path"[120] with his concept of the 'technological frame.' A technological frame can be thought of as a frame of meaning that shapes the way future groups understand and react to a technology. The frame is built up from the "set of practices and the material and social infrastructure"[121] around an artifact, and is applicable to all social groups. Unfortunately, this concept still suffers from the theoretical incompatibility between realism and radical constructivism. Bijker states, in a move apparently opposed to radical constructivism, that technology cannot have "unbounded flexibility," but is constrained by "the solidity and momentum of sociotechnical ensembles":[122]

> Can relevant social groups fantasize whatever they want, without constraints? Of course, they cannot. Attributions of meaning are social processes and, as such, are bound by constraints. Previous meaning attributions limit the flexibility of later ones, structures are built up, artifacts stabilize, and ensembles become more obdurate.[123]

And so, though Bijker recognizes that not all technological interpretations can be "wished away," he attributes this "obduracy" to vague *social* "constraints," "structures" and semiotic inertia. No where in his description of the constraints on interpretation do technical or natural facts figure in.

Why do Bijker, Pinch and other scholars choose to employ radical constructivist rhetoric, especially if it doesn't contribute to, nor is it supported by, their

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119 Kline, Ronald, and Trevor Pinch. 1996. Users as Agents of Technological Change: The Social Construction of the Automobile in the Rural United States. *Technology and Culture* 37
120 Pinch. The Social Construction of Technology: A review
121 Sismondo, Sergio. 2004. *An Introduction to Science and Technology Studies*. Oxford: Blackwell Publishing, 83.
122 Bijker, Wiebe. 1997b. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge, MA: MIT Press, 281.
123 Ibid., 281.

empirical research? Sismondo, supported by a quote from Barnes, provides a compelling explanation for this tendency of mild constructivist scholarship to "adopt the … radical, constructivist claim as a slogan [and yet] ignore it in practice"[124]. The impression from reading some constructivists texts that:

> . . . reality has nothing to do with what is socially constructed…we may safely assume …is an accidental by-product of over-enthusiastic sociological analysis, and that sociologists as a whole would acknowledge that the world in some way constrains what is believed to be.[125]

Sismondo's "sketch of an answer" to the question of why "sociologists of science come to hold that nature can be literally constructed" in the radical sense, is equally applicable to sociologists of technology:

> Detailed studies of actual scientific activity seem to indicate that there exists a large amount of contingency in our scientific knowledge before it stabilizes. The intuition is that 'It could easily have been otherwise.'[126]

Furthermore, the methodological agnosticism required by constructivist sociologists about "truth" and the "workability" of a technology easily leads to an ontological agnosticism (or relativism) about truth and materiality, a theoretical slip referred to by realists as the "epistemic fallacy" because epistemology (what we can know) is conflated with what is (ontology).[127]

One final reason why radical constructivist rhetoric is frequently adopted in the study of technology has to do with the ways research programs position themselves relative to each other to emphasize (or construct) their epistemic importance. Constructivist scholarship of technology is forced to respond to criticisms, like those of David Edgerton, that (mild) constructivism offers nothing new to the study of technology. Scholars of technology have long accepted the "embeddedness of

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124 Sismondo. Some Social Constructions.
125 Ibid.
126 Ibid.
127 Ibid., 535.

technology in the human world"[128] – SCOT and other constructivist approaches is just a repackaging of what everyone already knew. In response to this, Trevor Pinch deflects Edgerton's criticism by saying that it is "directed towards the mild form of social constructivism. And perhaps he is right." Radical constructivism, Pinch avers, offers something radically new and noteworthy.

In other words, scholars who embrace radical constructivist claims may do so as a means of distinguishing their scholarly enterprise from the more humdrum, mainstream, and well established history of technology. If Sismondo and I are correct in arguing that radical constructivism is grounded in weak arguments and is not necessary for the actual work done by self-labeled radical constructivists, then constructivist scholars should not brush off mild constructivism by saying that "the stronger [radical] form of social constructivism does offer something more."[129] Instead, when responding to criticisms like those of Edgerton, constructivists should expand on the less exciting, but more tenable and important claim that "mild social constructivism allows historians to repackage what they have always done in a new way."[130]

Mild social constructivist approaches have much to offer the study of technology. Constructivism offers a more nuanced understanding of how different groups interpret the meaning of technology differently and thereby shape the future evolution of the technology by advocating, consuming, and 'hacking' in ways that promote certain interpretations over others. Constructivism also reminds scholars that the very perceptions of a technology's desired functionality and technical properties can be partly shaped, through advertising, ideology, and other social processes.

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128 David Edgerton quoted in: Pinch. The Social Construction of Technology: A review
129 Ibid.
130 Ibid.

Constructivism raises the awareness of how artifacts may embody and reinforce a certain politics.[131] Returning to the theoretical antagonism that helped give rise to constructivism, social constructivism challenges simplistic 'just so' technologically deterministic historical narratives. Thus, social constructivism may be a repacking of what has always been done by most historians of technology, but it is a repacking that adds considerable value in the attention it draws to the social, contested, path-dependent and political. Radical constructivist rhetoric is not needed to justify the novelty and value of social constructivism. Radical rhetoric is also unhelpful because it hinders scholarly cross fertilization.

Technological Momentum (or SCOT + Sunk Costs)

Historian Thomas Hughes, also unsatisfied with either intellectual extreme, sought "an alternative to technological determinism and social construction"[132] in the concept of technological momentum. From his study of energy systems, Hughes found that while technological systems are well described by social constructivism when the they are young, as the systems mature and grow they seem to gain an inertia, which is often confused for autonomy: "they have a mass of technical and organizational components; they possess direction, or goals; and they display a rate of growth suggesting velocity."[133]

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131 See, for example:
Winner. Do Artifacts Have Politics.
Noble, David. 1986. *Forces of Production: A Social History of Industrial Automation*. Oxford: Oxford University Press
Latour, B. 1992a. The Sociology of a Few Mundane Artifacts. In *Shaping Technology/Building Society*, edited by W. Bijker and J. Law. Cambridge, MA: MIT Press

132 Hughes, Thomas P. 1983. *Networks of Power - Electrification in Western Society, 1880-1930*. Baltimore: Johns Hopkins University Press, 295.

133 Hughes, Thomas P. 1987. The Evolution of Large Technological Systems. In *The Social Construction of Technological Systems*, edited by W. E. Bijker and T. Pinch. Cambridge, Massachusetts: MIT Press, 76.

Hughes' theoretical contribution can be conceptualized in the language of "sunk costs": assets have been bought, standards set, employees trained, social networks formed, interactions routinized, and vested interests entrenched, all of which reinforce earlier technological choices. Members of a mature technological system facing future decisions will be biased towards the use of those assets—be they technical, economic, social, or political—already in place.

A particularly stark example of the effects of sunk costs comes from the Muscle Shoals Dam. This massive hydroelectric dam was constructed during World War I to provide the energy needed to manufacture nitrogen compounds. Hughes writes:

> Muscle Shoals Dam … became a solution looking for a problem…. In 1933 [it became part of] a regional development project of enormous scope…. This durable artifact acted over time like a magnetic field, attracting plans and projects suited to its characteristics.[134]

The concept of technological momentum finds resonance in the works of many other scholars. Hughes notes that technological momentum is similar to, but even more obdurate than, the iron-cage fate of Max Weber's bureaucracies. Anthony Giddens argues for a theory of structuration in which the actions of individuals establish the structures which constrain the actions of future individuals. Bijker introduces the concept of the "technological frame" which is built up from the "set of practices and the material and social infrastructure"[135] and thus constrains, with its "solidity and momentum" the flexibility of future technological choices and interpretations.

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134 Katz, Eric, Andrew Light, and William B. Thompson, eds. 2003. *Controlling Technology: Contemporary Issues*. Amherst, NY: Prometheus Books, 293.
135 Sismondo. *An Introduction to Science and Technology Studies*, 83.

In short, "men make history, but under circumstances … transmitted from the past."[136] Technological systems are still designed, built, and altered by and for people, but individuals at any point in time face a choice set largely determined by the acts of their predecessors.

Actor-Network Theory

Unlike SCOT and Technological Momentum, Actor-Network Theory (ANT), as a research enterprise, was not born from a single or small set of programmatic publications, nor does it today have a single axiomatic expression. In the flagship text[137] that, as the story goes, launched the constructivist enterprise into technology, two articles by Michel Callon and John Law can be read as ancestors to the ANT tradition. More generally, ANT can be traced back to the work of Michel Callon, John Law, and Bruno Latour.[138] Describing an intellectual lineage for ANT is easy, however, compared to the task of summarizing what is a self-consciously anti-essentialist scholarly enterprise. John Law writes that he "feels uncomfortable" when asked to summarize ANT. What does it mean, Law asks, "to be a 'faithful representative' [for] a theory that talks of representation in terms of translation [and] seeks to undermine the very idea that there might be such a thing as fidelity [, of] faithful translation."[139] If one of the founding and still contributing scholars of ANT

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136 Marx, Karl. 1963. *The Eighteenth Brumaire of Louis Bonaparte*. New York: International Publishers (original publication date 1851)

137 Bijker, Hughes, and Pinch, eds. *The Social Construction of Technological Systems*

138 Some example publications include:
Callon, Michel. 1986. Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St. Brieuc Bay. In *Power, Action and Belief*, edited by J. Law. London: Routledge;Latour, Bruno. 1987. *Science in Action: How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press;Law, John, ed. 1986. *Power, Action and Belief*. London: Routledge & Kegan Paul

139 Law, John. *Traduction/Trahison: Notes on ANT*. Department of Sociology, Lancaster University, 1997 [accessed 10/07/2005]. Available from http://www.cs.ucsd.edu/users/goguen/courses/175/stslaw.html.

has difficulty summarizing ANT, then any attempt to do so must be read with caution. Nonetheless, as one of the most productive theoretical frameworks used in the study of technology, ANT must be accounted for. In the following section I will summarize and criticize some of the theoretical insights of ANT, as well as begin my own translation of ANT to serve my interests in this paper.

Actor-Network Theory began as a sociology of science and technology, or in Latour's phrase: technoscience.[140] ANT conceptualizes the creation of knowledge and technologies by analogy to Machiavellian power politics, where political actors seek to ally themselves with other actors in such a way as to maintain and increase power against hostile external alliances (or networks). A scientist or technician "enlists" allies, who may be both human and material, to support their claim to "truth" or "feasibility," and hence power. Latour gives the example of Rudolf Diesel who sought to build a new engine. In order to do so, Diesel needs to build a reliable network of allies, including engineers and scientists, investors and entrepreneurs, as well as pumps and fuel. Concerning the latter, Diesel had to "shift his system of alliances"[141] when he was "betrayed" by his various early fuels which refused to ignite under high pressure. A successful technology must accommodate the "interests" of both consumers, engineers, legislatures, and businessmen, as well as physical processes, materials, and other technologies.

Laboratories are such powerful centers of knowledge production because they are able to interrogate actants (such as electrons, gravity, chemicals and stars) by making them human scale, and by subjecting them to tests that reveal their interests and their potential fidelity to different political projects. These tests also allow scientists, through "inscription devices," to "transform pieces of matter into written

140 Latour. *Science in Action: How to Follow Scientists and Engineers through Society*
141 Ibid., 123.

documents."[142] These inscriptions are called "immutable mobiles" because they have been abstracted from their context and can then be transported to other contexts.[143] Laboratories, thus, allow scientists and technicians to break Nature into components, to stabilize those components, and then translate them into other more mobile forms, such as a graph or standardized compound – all for the purpose of enlisting reliable and mobile allies for the political purposes of the network builder.

One of the main methodological principles of ANT, then, is to treat social and technical elements "super-symmetrically." David Bloor famously laid out the tenets for the Strong Programme of the Sociology of Scientific Knowledge, one of which was that an analyst should be symmetrical in her causal explanations of "true and false beliefs."[144] ANT extends this principle by acknowledging that:

> . . . the ingredients of controversies are a mixture of considerations concerning both Society and Nature. For this reason we require the observer to use a single repertoire when [case studies] are described. . . . The principle of generalized symmetry [states that] we must respect. . . not to change registers when we move from the technical to the social aspects of the problem studied.[145]

ANT conceptualizes the world as a "seamless web" of actants that are incorrectly traditionally dichotomized as either the Social or the Technical. John Law coined the term "heterogeneous engineering" to denote the ways engineers must configure both the social as well as the technical in order for a technology to function coherently.[146] Latour provides a charming illustration of this in a discussion of the

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142 Latour, B., and Steve Woolgar. 1979. *Laboratory Life: The Construction of Scientific Facts*. Princeton, NJ: Princeton University Press

143 Latour, B. 1990. Drawing Things Together. In *Representation in Scientific Practice*, edited by M. Lynch and S. Woolgar. Cambridge, Mass: MIT Press

144 Bloor, D. 1976. *Knowledge and the Social Imagery*. Chicago: University of Chicago Press

145 Callon. Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St. Brieuc Bay

146 Law, John. 1987. Technology and Heterogeneous Engineering: The Case of Portuguese Expansion. In *The Social Construction of Technological Systems*, edited by W. Bijker, T. P. Hughes and T. Pinch. Boston: MIT

difficulties of devising a wall-hole (a door) that will be open for researchers to enter and exit, but closed against the cold air entering and warm air exiting. One (technical) solution is to install a door with an automatic shutting mechanism, but these have problems, such as making it too difficult for some humans to open or slamming shut on slower moving humans. Another (social) solution is to "configure the user" through a sign that reads "The Groom Is On Strike, For God's Sake, Keep The Door Closed."[147] All technologies require some understanding on the part of the "user." Technologies do not exist independently of the social, but rather the two are seamlessly enmeshed.

Actor-Network Theory is born from work that emphasized the metaphor of translation. Callon talks about a "sociology of translation" wherein "translation" is the focal metaphor for a general social theory that can apply equally well to humans as non-humans (fulfilling the principle of super-symmetry). "Translation" refers to the:

> . . . moments [when] the identity of actors, the possibility of interaction and the margins of maneuver are negotiated and delimited… To translate is also to express in one's own language what others say and want, why they act in the way they do and how they associate with each other: it is to establish oneself as a spokesman. At the end of the process, if it is successful, only voices speaking in unison will be heard.[148]

If ANT is to be summarized in one word, it is "anti-essentialist." John Law writes, in what is the closest thing to a summary of ANT as one will find, that the overriding theme of work categorized as ANT is that,

> Essentialist divisions are thrown on the bonfire of the dualisms. Truth and falsehood. Large and small. Agency and structure. Human and non-human. … Materiality and sociality. …Though [ANT's anti-essentialist] scandal may sometimes be more metaphysical than practical… Actor-Network Theory is, has been, a semiotic machine for waging war on essential differences.[149]

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147 Latour. The Sociology of a Few Mundane Artifacts
148 Callon. Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St. Brieuc Bay
149 Law, John. 1999. After ANT: complexity, naming and topology. In *Actor Network Theory and after*, edited by J. Law and J. Hussard. Malden, MA: Blackwell Publishers

This approach is consonant with the constructivist propensity to reject claims about the essential nature of technologies. ANT, however, takes this movement further, or reflects it across another axis of symmetry, by arguing against traditional SSK which believes that "Nature is uncertain but Society is not."[150] Thus ANT also rejects the essentialization of Society. What is left is a set of seamless networks that translates the interests of other actants and networks so as to avoid dissolution by other hostile networks.

This anti-essentialist predilection of the scholars whose work has been grouped under the heading of Actor-Network Theory explains why in an edited volume on ANT a reader finds not summaries of the axioms and corollaries of Actor-Network Theory, but an insistence to move beyond the fixity of names and "a notion of theory that says that it is or should necessarily be simple, clear, transparent."[151] Bruno Latour, in his chapter, cites "four things that do not work with actor-network theory: the word actor, the word network, the word theory and the hyphen!"[152] On this note, I will criticize two elements of the above representation of "Actor-Network Theory" before also moving onward.

Does it make sense, as John Law and other ANT scholars suggest, to "treat natural and social adversaries in terms of the same analytical vocabulary"?[153] On the one hand, I share this methodological premise: theoretical generalizability and cross-disciplinary dialogue are epistemological virtues. If we can analyze Nature and Society with the same conceptual tool box, then we can finally move beyond the intellectual limitations that have kept the study of sociotechnical reality

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150 Callon. Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St. Brieuc Bay
151 Law. After ANT: complexity, naming and topology
152 Latour, B. 1999. On recalling ANT. In *Actor Network Theory and after*, edited by J. Law and J. Hassard. Malden, MA: Blackwell Publishers
153 Law. Technology and Heterogeneous Engineering: The Case of Portuguese Expansion

unsatisfactorily divided into the various disciplines of the social sciences and engineering. ANT, however, proposes a theoretical unification by the translation of treating all things like humans: all things have interests and the ability to strategically translate the interests of others to suit one's purposes. There are three problems with this argument.

The first problem is that human actors and material actants may be sufficiently different from each other to warrant separate analytical tools. The ANT solution, to treat material actants *as if* they were intentional, strategic, self interested political actors, dilutes the meaning of 'interests' and 'intentionality'. The concepts of "interests" and "strategic intentionality" connote a number of behavioral characteristics: a tendency to strive towards some goal, the ability to enact a number of strategies to achieve said goal, the ability to act with foresight (in Jon Elster's words, "one step backward, two steps forward"), and the ability to act strategically against those who oppose their interests and collectively with those who share their interests. Sociotechnical scientists, in other words, should be able to make the same distinction between intended and accidental behavior that, according to Justice Oliver Wendell Holmes' aphorism, dogs do when they distinguish "between being stumbled over and being kicked."[154] When John Law describes the "struggle between the Atlantic and the galley [where] the Atlantic was the winner" because it was "a stronger adversary," he is indulging in a form of anthropomorphism that humans have elaborated since Zeus tossed lighting bolts. These entities, the Atlantic and lightning, have been challenges for human networks, yes. But they were indifferent, oblivious, adversaries. The Atlantic did not adapt or act strategically in the struggle against the Portuguese (say by vindictively flooding Portuguese ports, or by giving fair sailing weather to the

154 Holmes, Oliver Wendell. 1881 (1991). *The Common Law*. London: Dover Publications

enemies of Portuguese), nor did it have any particular *reason* for opposing Portuguese vessels. The imposition of intentional language on to a non-intentional entity only serves to dilute the meaning of our intentional vocabulary, when the simpler causal language of the natural sciences suffices to explain non-living phenomenon.

The second problem with ANT concerns what it means to be able to translate an actant's interests. First, to clarify terminology, I use "preferences" whenever possible to indicate the most fundamental priorities of the actor. From those basal preferences are derived instrumental "goals," "means," or "interests" that inform strategies that are most likely to satisfy the underlying preferences. "Interests," then, are derived from the basal preferences and dependent on the strategic context.

There are three interpretations of the claim that actors/actants translate each other's interests, which I'll call 1) radical, 2) game theoretic, and 3) differential. 1: The radical interpretation, like radical constructivism, would argue that interests and preferences are completely flexible and subject to unrestrained social construction. All priorities and identity are subject to socialization and modification. 2: The game theoretic interpretation would argue that actors have a set of basal preferences (a utility function) which are, at least partially, unmalleable. Preferences or interests can be "translated," then, to the extent that one actor can restructure the payoff matrix facing another actor through intervention or the provision of information. Pasteur, for example, was able to convince the French army that support for his research was a means to achieve their underlying preference of having a strong army. In this interpretation, then, the French army's basal preferences were not distorted or manipulated, rather, the means to achieve those interests were clarified. This distinction is congruent with, but the inverse of, that made by SCOT regarding the interpretive flexibility of the bicycle. In the bicycle case, the actors agreed on the technical properties of the Ordinary (as dangerous), but differed over its derived

meaning (since they had different preferences). In the case of Pasteur, the French army (game theoretically speaking) had constant preferences, but modified its instrumental means due to informational differences. 3: The mild or differential interpretation – a compromise position -- would argue that though the interests of actors may be fundamentally malleable, for the most part they differentially resist certain translations, depending on the obduracy of the particular interest and the degree of translation. Thus, though there are occasions when the most fundamental of human preferences,[155] self preservation for example, is reinterpreted through effective "translations" by ideologues (for example, by using promises of the afterlife), for the most part, people obdurately reject this translation.

A third aspect of ANT's ontology of strategic actants deserves discussion. ANT's ontology runs counter to the unifying epistemological tendency in most other disciplines to treat more and more of the social world as if it were explainable by reductionistic, mathematical laws. Game theory in political science and economics reduces strategic interaction in general into mathematically specifiable and tractable situations. Economics seeks to model human behavior and long-term economic processes according to precisely defined mathematical models. Mathematical reductionism seeks to explain human interests and alliances in terms of their (at least partly) endogenous objective interests and rational strategic calculations. ANT, on the other hand, wants to open up the deterministic (and hence mathematically reductionist) world of the natural sciences and engineering to the indeterminate Machiavellian intrigue of uncertain alliance building and the unconstrained translation of perceived interests. On the other hand, this may not be a "problem" with ANT, but

155 I do not assume, nor do I need to, that all humans share the same fundamental preferences, nor that individual humans have the same fundamental preferences throughout their lifetime. What is important for this argument is that humans have preferences that are partly independent of their social environment.

may be its virtue, since it provides an alternative universal ontology for explaining sociotechnical phenomenon to the dominant mathematically reductionistic paradigms.

Herein lies ANT's ontological paradox. On the one hand, ANT can be read as offering a realist, materialist ontology – identical to that offered by the mathematically reductionistic social sciences. On this reading of ANT, the world consists of actants who exist in strategic networks or alliances, and seek to dissolve rival networks while reinforcing their own. In this world there are real contests of power going on, with outcomes determined, presumably, by characteristics of the respective networks. This is a world where interpretive meaning is shaped by the victorious alliance - since rival networks each desire conflicting interpretations of technologies and truth, they must resolve these conflicts through appeal to power. Though ANT scholars never specify exactly how power should be measured, aside from conceptual hand-waving about the "size" of the network,[156] they implicitly support the notion that there is some calculus of power, based on the ability to enlist allies, to dissect, stabilize and mobilize actants, to make of oneself an obligatory passage point for all others, and so forth. This is a realist, materialist ontology which is susceptible, in theory at least, to the measurement, specification, and logical formulation undertaken by the other realist, social sciences.

On the other hand, ANT scholars share an epistemological tradition of challenging essentialist and causal claims, and more generally, of just being challenging. Bruno Latour and John Law both recently laid their claim to the future

[156] ANT scholars never specify how one would measure the "size" of a network. Do we sum the mass of its parts? Do we measure the volume of space the network occupies? Do we count the number of humans? We could never count the number of actants, since there is no definition about what is (or more accurately, what is not) an actant. While the above metrics that I have suggested each have some evidence to commend it, they offer a very simplistic adaptive topology for which it would be easy to provide counter-examples. Perhaps ANT scholars should look to the work of technological determinists, who have explored this problem in much more rigor.

agenda for ANT. Latour, Cheshire Cat like in his pleasure at making semi-logical, often self-contradictory, theoretically challenging arguments, argues that,

> ANT is a way of delegitimating the incredible pretensions of sociologists who, to use Bauman's forceful expression, want to act as legislators and to open yet another space for interpretive sociology. …[ANT realized that] it could not stick to a theory of social order [because] the whole theory of society soon appeared to be enmeshed in a much more complex struggle to define an epistemological settlement about: a) what the world is like *outside* without human intervention; b) a psychology *inside*—an isolated subjectivity still able to also comprehend the word [*sic*] out there; c) a political theory of how to keep the crowds at bay without them intervening with their unruly passions and ruining the social order; and finally d) a rather repressed but very present theology that is the only way to guarantee the differences and the connections between those three other domains of reality.[157]

Latour, instead of endorsing either an idealist or materialist ontology, seems to prefer the uneasy middle ground of supporting, as well as undermining, the pretensions of both.

Whereas Latour lays out an agenda which seems to embrace every form of investigation, from science to interpretive sociology to theology, John Law rejects simple, totalizing, generalizing claims to knowledge, preferring an open, undefined, disorientating, ontology:

> What I am trying to do is attack simplicity---and a notion of theory that says that it is or should necessarily by simple, clear, transparent…The God eye[158] is alive and well and seemingly incurable in its greed for that which is flat and may be easily brought to the point. But, or so I firmly believe, the real chance to make differences lies elsewhere. It lies in the irreducible. In the oxymoronic. In the topologically discontinuous. In that which is heterogeneous. It lies in a modest willingness to live, to know, and to practice in the complexities of tension.[159]

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157 Latour. On recalling ANT

158 The 'God eye' refers to the outsider epistemological perspective presumed by most sciences: that we, as observers, can separate ourselves from our own history and our own partial perspective. The God eye strives to abstract the generalizable from the partial and specific.

159 Law. After ANT: complexity, naming and topology

To summarize, Actor-Network Theory does not have a singular ontology or theoretical contribution. The most central practitioners of ANT reject the label "Actor-Network Theory," and any attempt to limit the meaning or possibility of their work. Actor-Network Theory, then, should better be thought of as a family of research which is sometimes contradictory, sometimes complementary, and never closed to dialogue and argument with other epistemologies and ontologies.

Technological Politics and Technical Power

Implicit to all, except radical constructivist, accounts of technology is the idea of power: the ability of some groups to achieve outcomes against the will of others. Mild constructivism, as Stewart Russell pointed out,[160] risks a simplistic pluralist model of social negotiation if power and social structure are not taken into consideration. Rather, during a process of social negotiation different groups strategically mobilize their resources and allies to achieve their preferred outcomes. Furthermore, relevant social groups themselves are not unitary actors, but are often beset by internal conflicts of interest which can affect the outcome of social negotiations. Analysts employing the idea of technological momentum introduce a temporal concept of power, in which present day social groups have power over the future, through the construction of obdurate artifacts, ideas, social networks, and systems. Actor-Network Theory centrally employs an, unfortunately under-theorized, concept of power; under ANT various social networks mobilize allies to defeat rival networks, though it is unclear exactly what allows one network to succeed over another.

160 Russell, Stewart. 1986. The Social Construction of Artefacts: A Response to Pinch and Bijker. *Social Studies of Science* 16 (2)

Technologies thus evolve in the context of social negotiation among groups with different degrees and kinds of power. For example, consumers, engineers, and politicians all have different kinds of power affecting the construction of technologies. Technologies also have political consequences, and therefore can be used to reinforce political objectives, the classic (apocryphal) example being Robert Moses' racist bridges, as described by Langdon Winner. With these two premises—that the social construction of technology is biased towards the interests of the powerful, and that technologies themselves can have profound political consequences—a classist (or Marxist) theory of technology becomes tenable. Under an extreme interpretation, technologies are a product exclusively of the interests of the powerful classes, and serve only to further reinforce their interests and power. Under more modest interpretations, technologies have social and political consequences of which we should be more aware, for example, the lay-out of furniture will structure social interaction.[161] David Noble, Richard Sclove, and Langdon Winner, among others, have explored these issues, and, especially the latter two, have looked at ways to better democratize technological decision making. Langdon Winner explains that: "technological innovations are similar to legislative acts or political foundings that establish a framework for public order that will endure over many generations."[162] Just as legislation and the constitution should be of concern to all citizens, so should the shape of our technologies be seriously debated by political bodies.

From the perspective of technological politics, the perception of deterministic or autonomous technological systems may in fact be the interests of the ruling class expressed *through* technologies. Thus, the majority of people, in the first and

161 Sclove, Richard. 1995. *Democracy and Technology*. New York: Guilford Press, 13.
162 Winner. *The Whale and the Reactor - A Search for Limits in an Age of High Technology*, 29.

especially third world, may correctly perceive technological systems structuring their world, whether it be through new workplace technologies that increase control or the social dislocations of globalization and the IT revolution. In all these cases, the scholars of technological politics would argue, while it is true that certain technological changes are inducing other social or political changes, these technological changes are themselves caused by—often hidden—political forces. Thus, the claim of the technological determinists that (most) people are losing agency to rationalizing forces may be largely correct; it should, however, be nuanced to appreciate that the cause of these powerful rationalizing forces are not immutable technical trends or necessary laws of history, but the ever-present interests of the powerful.

Another significant theoretical corollary of considering technologies as a product of, and a factor in, power-laden social negotiations arises. Imagine a hypothetical social negotiation where two equally powerful social groups are each trying to realize their preferred technical design. If one technical design conveys significant power to the group that adopts it, then this social negotiation will be resolved in favor of the more powerful technical design *because* of the technical properties of the artifact. In other words, powerful technical designs (or interpretations or uses of technologies) are more likely to dominate because of the advantage conveyed to those groups who prefer it. It is thus theoretically possible that some technical designs will convey sufficient power that, so long as some group adopts it for whatever reason, the design will be implemented and will proliferate. Thus, SCOT + technical power => the possibility of technical determinism.

Scales of Analysis

Misa's Correlation

Thomas Misa has surveyed the scholarship studying the social role of technology and found an important correlation. Larger scale (macro) studies are more likely to be technologically deterministic than smaller scale (micro) studies. Misa found that philosophers of technology are the most likely to be technologically deterministic and also tend to have the largest scale of analysis. Furthermore, in order of diminished technological determinism and smaller scales of analysis are: business history, urban history, physical science history, technological history and labor history. Labor history, the most constructivist and micro, emphasizes the many ways workers have challenged, transformed and rejected new technologies. That is,

> macro or micro [scales of analysis]. . . correlate with disciplinary traditions of affirming or denying technological determinism. Similarly, within each discipline, the authors affirming some version of technological determinism adopt a 'macro' perspective, whereas those denying technological determinism adopt a 'micro' perspective.

Misa illustrates his point using the following diagram:

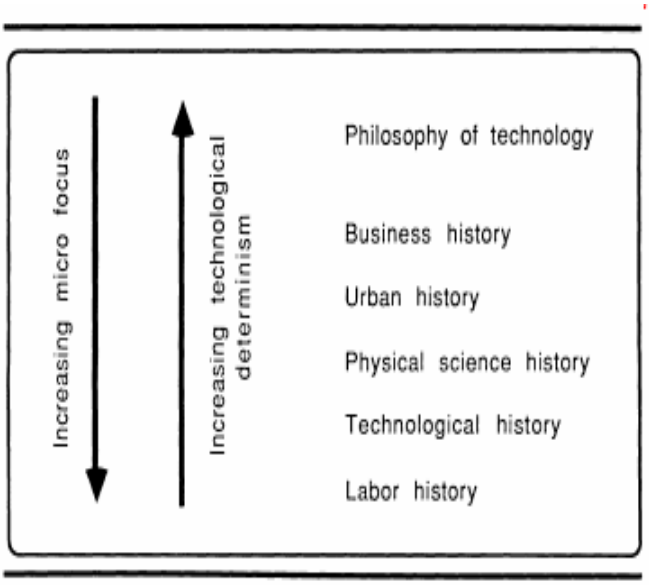

Figure 1 - Misa's Correlation: Macro = Deterministic[163]

Misa's diagram provides an entry point to a systematization that I develop in this paper of different theories of sociotechnical systems, which I will elaborate in the section on sociotechnical evolution. Rather than listing different disciplinary approaches to the study of technology like Misa, I have arrayed different scholarly approaches to studying technology based on their theoretical premises, which themselves correlate with disciplinary traditions. The bottommost theories (most white) are the most constructivist, have the smallest scales of analysis, and assign the greatest agency to individuals. The top most theories (most black) are the most deterministic, tend to have the largest scales of analysis, and assign the least agency to individuals.

[163] Misa. How Machines Make History.

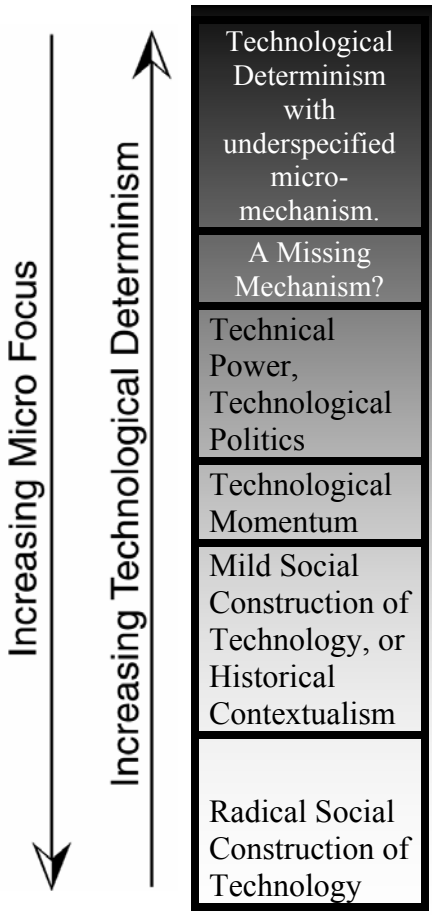

Figure 2 - Theories of Technology from Micro-Constructivism (White) to Macro-Determinism (Dark)

From Misa's correlation he concludes that the higher the scale of analysis (the more black), the easier it is to invoke 'the Machine' as an actor, to personify an abstraction. Because philosophers and other macro-scholars look at such a sweeping range of phenomena, they are susceptible to erroneous abstractions, such as positing that a machine can be a historical actor. Were these macro-scholars to take a closer, more detailed, analysis, they would find that machines are mere constructions of humans, and that it is humans, and only humans, who are historical actors. Misa writes:

> Again and again, historians writing large-scale or deterministic accounts deploy the Machine to structure social change, while as soon as the historical microscope is unveiled, the Machine as such dissolves. This causal chain results

> from the exigencies of synthesis and the assumptions .. inherent in a macro viewpoint. From a shop-floor perspective, the Machine is an irrelevant abstraction, and what makes history is individuals (perhaps classes) in conflict or accommodation. A row of machine tools is not itself a compelling historical agent.[164]

Misa's correlation holds for all the determinists and constructivists surveyed in this paper. The technological determinists tend to look at sweeping histories, abstract general trends, archeological remains spanning centuries, and economic data, from which they read patterns and attribute historical causality to technological change. The social constructivists, on the other hand, look more closely, watch the human actors, record their speech, and read their letters, and they see humans making history. At their scale of analysis it is, as Rosalind Williams writes, "self-evident" to the social constructivists that "human beings construct machines, not the reverse."[165]

Implicit to this constructivist critique is an epistemological belief: the findings of micro-analyses are epistemologically superior to—are more "real" than—those of macro-analyses. While I agree with the epistemological prior that any macro analysis should be, ultimately, ontologically congruent with a micro-analysis of the same phenomena, as a methodological principle it is dangerous to privilege micro-analyses. In complex systems, there are often emergent patterns visible over larger scales of analysis which may be impossible to derive from the findings of smaller scales of analysis. If such large scale, emergent patterns are observed, then scholars should seek to find an explanatory mechanism. The absence of a plausible mechanism, though, does not warrant the dismissal of the findings from the larger scale of analysis and the privileging of the findings from the smaller scale of analysis. To elaborate this

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164 Misa How Machines Make History, and How Historians (And Others) Help Them, Science, Technology, & Human Values, Vol 13, no. 3/4 1988
165 Williams. *Retooling: A Historian Confronts Technological Change*, 116.

point, I will provide a short scholarly parable about a hypothetical community of "Wave Studies" scholars.

The Lunar Determinist: A Parable

A young sandcastle consultant who was concerned about the water waves that interfere with his client's castles went to the annual Coastal Wave Studies Conference to present a new theory he was working on, and to better understand these waves. He said to the conference attendees: "I've been watching my beach for a few days now, and I noticed that the sandcastles built highest on the beach only touch water when the moon is directly overhead, so **I think that the moon somehow causes day long waves—or "tides"—in the ocean."**

The consultant's proposal was not well received. A senior scholar stood up and declared that in his own detailed analysis of one square decimeter of ocean over the span of three seconds, he demonstrated the complex hydrodynamics of a passing breeze that creates little waves. "I won't deny your acclaimed passing breeze theory of waves" said another scholar, "but I've found the largest cause to be, in my twenty minute analysis of a diving area, rotund boys who do cannonballs into the water." Still another scholar pointed out how, in his one hour analysis of a beach, large passing boats were the single most important cause of large waves. "In all the research to date," said the first, "the only mechanism for wave formation is physical interaction, be it the displacement of water by passing boats or the influence of wind patterns. Since the moon does not physically interact with water or wind, as anyone can plainly see, these findings must be mistaken." Other senior scholars agree that this theory is totally un-tethered to the self-evident reality observed through micro-studies, and opt to label this kind of reasoning "lunar determinism," liberally dismissing any future scholars who make similarly misguided claims.

This "Wave Studies" parable illustrates two elements of the technology studies impasse: first, studies at different scales of analysis can (and often do) find different processes to be important; second, dismissing a macro-observation (or a whole library of them) because no one has yet found a plausible mechanism for their occurrence is intellectually misguided. The patterns described by the technological determinists ought to not be entirely dismissed simply because no one has yet found a plausible mechanism for their existence. It is a common feature of complex systems that micro processes will give rise to emergent properties at a higher level of organization. For example, as if by magic, highly disordered and unpredictable gas molecules give rise to Boyle's predictable gas law, the chaotic and uncoordinated actions of the market give rise (when factors are priced correctly) to an efficient allocation of resources, the incomprehensible firings of millions of neurons give rise to human thoughts. Likewise, the varied perceptions, and contingent and largely free actions of billions of individuals may, in theory, give rise to deterministic long-term trends.

Epistemological Responses to Conflict: Dismiss Other or Seek Nuanced Synthesis

When two scholarly communities purportedly studying the same phenomena come to seemingly contradictory results, an epistemological choice must be made. Either 1) each community can dismiss the findings and claims of the other, or 2) the communities can seek to understand what assumptions, methods or logics cause such divergent findings, and thereby work towards a coherent synthesis. Perhaps the two communities are not in fact studying the same phenomena? If not, what parameters define the relevant phenomena for each community? Perhaps each community is

based on fundamentally different assumptions? If so, what evidence or reasoning exists to support either assumption, and in what contexts?

The study of technology faces such an epistemological dilemma. Serious scholarly communities radically disagree about the relationship between technological and social change. Winner summarizes the contradiction facing the study of technology well:

> … at the very moment that notions of contingency and social construction of technology have triumphed among social scientists and philosophers of technology, in the world at large it appears that the experience of being swept up by unstoppable processes of technology-centered change is, in fact, stronger than it has ever been. Social scientists may call them naïve, but the perception that institutions and individuals are driven by ineluctable technological change is fairly widely embraced among those who work in fields of computers and telecommunications, … who write on the emerging global economy [and amongst] economists and businessmen.[166]

And, I would add, amongst military planners, and most scholars of large-scale historical change.

I propose that it is time to seek theoretical synthesis through mutual intellectual respect. The label of "technological determinism" has been used as a rhetorical gate keeping device to dismiss scholars whose findings happen to disagree with the dominant approach within the social study of technology. Instead of taking seriously the perception amongst many other scholars and non-scholars that technology seems to be autonomous and strongly determining of historical change, the social study of technology has caricatured and dismissed all such claims. The label of "technological determinism" has, in effect, allowed constructivist scholars of technology to assume their desired conclusions by using the following logic: all scholars worth listening to find technology to be socially constructed and contingent; if a scholar finds otherwise,

166 Winner. Technology Today: Utopia or Dystopia?

they are not worth listening to; therefore technology is socially constructed and historically contingent. A research community's major theoretical findings should not become their required axioms for admission to scholarly dialogue.

If we wish to criticize a technological determinist, we should do so on reasonable intellectual grounds. We may criticize Ellul and Mumford for failing to provide a plausible mechanism for their claims, we may point out that their findings seem to contradict those from the micro-social study of technology, we may argue that they pessimistically overstate the likely harm from new technologies. We ought not, though, to label them with our "critic's term" that serves only to silence the debate on the question of historical causality: the significance of human agency should be the results of our studies, not their premise.

But, until the determinists can provide a plausible mechanism for their claims, the constructivists are not obliged to seek a synthesis with the determinists' seemingly contradictory findings. Thomas Hughes has elaborated the mechanism of technological momentum to partly explain the technical shaping of society. Langdon Winner and Bruno Latour, among others, have argued that elite groups use technology to further their political ambitions: the elite control the technical shaping of society. But thus far none of these possible mechanisms can produce the full panoply of trends observed by the technological determinists. I will now elaborate a mechanism which, rooted in micro-social interaction, can give rise to the most extreme technologically deterministic claims.

Returning to the wave studies parable, the moon drives the tides through the mechanism of gravity, an invisible force even now hard to comprehend, and nearly impossible to observe on microscopic scales of analysis.[167] I argue that technology

[167] On small scales of analysis, gravity is by far the weakest force. Only through its additive nature does it come to exert the power with which we are so familiar.

drives history through the mechanism of *competition, both military and economic*, a process that operates most comprehensively over long-time horizons and, because it is internalized by actors as the drive for power and profit, nearly invisibly in micro-case studies.

Sociotechnical Adaptationism

Sociotechnical entities exhibit *variety*; for example, there are a breadth of styles of hammers, parenting and tax codes, and new variants persistently arise. Sociotechnical entities *proliferate* at different rates (some negative); certain styles of artifact, technique, and institution are reproduced, imitated, imported to other context, or expand in scale. Other styles—most styles—of artifact, technique or institution, of course, die out. Any population which has these properties of variation and differential proliferation[168] will evolve towards those configurations which were most favorable or adapted to proliferation.

The social constructivists are right to argue that humans exhibit an incredible variation in their interpretation of reality, and in their objectives. However, the adaptationists ask, what would happen to any individual or group that persisted in holding an interpretation of reality that was uneconomical or militarily impotent, in a word: maladaptive? While the severity of economic and military competition has varied over time, there has never been a place that has been lastingly exempt from this competition.

Sociotechnical adaptionists—also sometimes called social, cultural or technological Darwinists—investigate the competitive processes behind the differential proliferation of different sociotechnical entities. Adaptionists expect that

[168] Proliferation means both to increase in number and to grow in size. Both meanings are appropriate for selectionist processes, since proliferating entities may do both (eg. a successful firm may grow, spin-off new firms in other markets, and other firms may imitate them).

the population of sociotechnical entities will become more adapted to succeed with respect to the competitive—or selection—pressures. Sociotechnical Adaptionism is most compelling in contexts where sociotechnical variability is relatively broad and plastic (a large population in which successful traits are easily copied) and competition is intense and uncontrolled.

Selection: Competition for Scarce Resources

In the construction of technology (and more generally, in any living system) there will always be one or more factors that are scarce. Of all the technical possibilities, only some will find people willing and able to think them; of all the technical ideas, only some will find the writing materials, time, and a receptive audience to be shared; of all the promising technical designs, only some will find the resources to be tested; of all the technical prototypes, only some will be *selected* to be reproduced; and most importantly for the adaptationists, of all the sociotechnical systems only some will acquire the human, manufactured and natural resources to survive.[169] In order for a technical idea to be thought, communicated, tested, and mass-produced, scarce resources have to be allocated to that technology's construction. Thus, there is competition among potential technologies (and their advocates) for limited resources at every stage of their creation; the process by which this competition is resolved—*the selection environment*—will determine what kinds of technologies are constructed. To understand why sociotechnical systems (such as

[169] The above language treats non-humans as capable of action. In this respect, I agree with scholars of ANT that humans do not have a monopoly on the capacity for action. Evolutionary biologists will often speak about genes or simple life-forms as if they made decisions and had interests. I do not think that this language is necessarily dangerous anthropomorphism. It makes sense to speak about replicators as if they had interests (their own replication) and choices (the range of variation). Just as saying that a person learned to do X is short-hand for a complex neuro-physiological process of variation and selection, speaking about a replicator's interests and choices is shorthand for a complex evolutionary process.

states or firms) consist of the technologies that they do, adaptationists look at the competition for human, manufactured, and natural resources *among* these systems.

Sociotechnical adaptationists don't think in terms of specific technologies (artifacts, techniques or institutions), but in terms of proliferating populations of systems. A technology does not find use or replicate by itself; rather, it requires other factors, such as human input, instructions, electricity, raw materials, and so forth. The factors are all integrated into larger proliferating systems that compete with other systems (and with "nature") to acquire more of the scarce factors required for proliferation. In this sense, these largest sociotechnical systems (such as business firms and states) may be more appropriately called sociotechnical organisms because, like living entities, they are in the business of acquiring the factor inputs needed to sustain, grow, and reproduce themselves. Sociotechnical organisms do not share all of the traits that people tend to associate with other living organisms, however. As will be discussed below, this failure to map directly on to the evolutionary biology metaphor is not a theoretical problem, because 1) biological systems are only a subset of the evolutionary process, and 2) biological evolution is more complex than most people presume.[170]

Sociotechnical adaptationists look at the competition amongst large sociotechnical organisms—the highest levels of selection—because that is where most of the deterministic external "natural selection" takes place which constrains the dreams of many social entrepreneurs. Thus, even when analyzing the evolution of a particular technology, sociotechnical adaptationists tell large-scale narratives about

170 For example, the ideas that horizontal transmission of traits does not take place in nature and that the definition of the organism or individual is self-evident are both mistaken, as will be explained below.

economic and/or military conflict because it is only at the highest levels of selection that the functional adaptiveness of sub-systems can be properly understood.

Adaptationists argue that in a world of competition, sociotechnical organisms will evolve to be most adaptive for the particular competitive context. Thus, in a world of militarily competing states, states will evolve to be adapted to the creation and use of military power.[171] In a world of economically competing firms, firms will evolve to maximize profit through maximizing revenue and minimizing cost.[172,173]

Sociotechnical Variation

The logic of Sociotechnical Adaptationism is most compelling when sociotechnical entities (including humans) exhibit broad and plastic variety, which is ironically also the human condition preferred by radical social constructivists. Many other social sciences assume or infer that humans behave in a specific set of ways: economics usually assumes selfish, rational, all knowing, actors; some schools of sociology and anthropology state that humans are constrained by their cultural and institutional structures; psychology tends to explain human behavior by subconscious cognitive mechanisms, often rooted in evolutionary biology. Sociotechnical evolutionists, about whom more will be said later, are able to combine the adaptationist emphasis on selection pressures and an awareness of behavioral, cultural and institutional constraints, to construct rich, plausible narratives of historical change.

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171 For examples, see Spruyt, Hendrik. 1994. *The Sovereign State and Its Competitors*. Princeton, NJ: Princeton University Press;Tilly, Charles. 1992. *Coercion, Capital, and European States, AD 990-1992*. Malden, MA: Blackwell Publishers

172 This argument exists at the core of neo-classical and evolutionary economics. In the short run, individual firms will satisfice to meet the selection criteria, but in the long-run in an infinitely competitive market with a large population, the process of satisficing amidst continual competition will lead to optimal firm decisions.

173 In both cases, the sociotechnical systems always face two adaptive strategies: to refine the current system (eg. weapon or production system) or to pursue radical innovations.

There is much evidence supportive of the claim that humans and sociotechnical systems are capable of broad variation, which supports the preferred assumptions of the constructivists and adaptationists. Peter Richerson and Robert Boyd, in their excellent recent work on sociotechnical evolution, try to convey the breadth of human social variation:

> Consider, for example, the Copper Eskimo and the Trobriand Islanders. In the winter, the Copper Eskimo lived in snow houses built on the frozen sea. They obtained food by spearing seals at breathing holes in the ice, sometimes waiting motionlessly for hours in the bitterly cold darkness. . . . They dwelled in groups of families linked together by a web of reciprocity without chiefs or councils. On the Trobriand Islands, many families shared a large wooden house. They subsisted on yams and taro gardens that had been cleared and cultivated by hours of backbreaking labor in the humid tropical sun. They were ruled by a hereditary aristocracy with an elaborate system of rights and privileges based on membership in large matrilineally organized clans. Now add to the list nomadic pastoralists living in the starkness of central Arabia, the rice farmers of Java with their intricately nuanced social life, and the teeming economic and ethnic complexity of Los Angeles, and you will be convinced of the magnitude of human variation.[174]

In contrast with the social constructivists, the sociotechnical adaptationists take seriously—even exaggerate—the importance of technical properties in determining historical outcomes. In many ways, this difference is similar to that between an internalist and a mild constructivist history, in terms of whether the analyst emphasizes the technical properties or the social perception of those properties as determinant. This difference, it should be noted, shy of theoretical extremism (of the postmodern relativist or naïve economistic varieties) cannot be resolved theoretically, but only empirically. In some cases, the particular social circumstances surrounding a technology's evolution deserve more attention, in others, the social circumstances

[174] Richerson, Peter J., and Robert Boyd. 2004. *Not By Genes Alone: How Culture Transformed Human Evolution*. Chicago: University of Chicago Press, 19.

were secondary, if not largely irrelevant, in comparison to the technology's characteristics

Thus a sociotechnical adaptationist looks at competitive settings, and argues that a particular technology proliferated because it facilitated the proliferation of the larger sociotechnical organism; under economic competition, the technology helped the firm reduce costs or increase revenues, under military competition, the technology contributed to the power of the military complex. Sociotechnical evolution is rarely so clear cut in the real world—there are often countervailing selection pressures, and variation may be limited or path-dependent. The sociotechnical adaptationist analysis captures the extreme of intense selection and broad variation; the radical social constructivist analysis looks at the other extreme of weak selection and broad variation; and the many other approaches to studying technology are at a middle levels of selection and limited variation.

Competition: the Constraint on Action

Differential proliferation is most easily conceptualized in terms of competition. The ultimate consequence of competition between social entities for access to scarce resources is that the less competitive social entities will wither and eventually disappear, while the more competitive social entities tend to flourish. Thus, inter-group competition is one of the main causes of sociotechnical selection, and perhaps also the most interesting.

In a sufficiently competitive environment, the range of adaptive—and for any length of time, possible—behavior for a sociotechnical organism and its components is severely constrained. Under perfect competition, a firm has no option except to produce the optimal quantity of goods. Under mortal military threat, a state and people have no option but to mobilize their political and military resources as best that

they can for defense. Under competition, actors always have the full range of options trivially available to them, though, in the long run only the adaptive behaviors will succeed. From the point of view of an evolutionary analyst, it makes no sense to consider the severely maladaptive options available to organisms, since any organism that became thus maladaptive would no longer be around. This is why you find so few, if any, firms in a competitive market that, in the long run, consistently lose money; the same is true for states and military prowess.

In summary, competition constrains action, not in the immediate or proximal sense, but in the ultimate, evolutionary sense: in a competitive environment, any action/trait/behavior which is maladaptive will ultimately vanish from the population. Uncontrolled competition in a large population, when taken to the limit, removes all human agency from the system. The extent of agency present in any given context, then, cannot be decided *a priori*, but is an empirical question, though one that must be embedded in a coherent sociotechnical theory. This will be explored at greater length in the section on Agency, under Sociotechnical Evolution below.

Competition: the Motor for Technological Progress

Competition does not just "constrain" sociotechnical evolution, it also enables adaptive change by persistently redirecting resources to a functional subset of sociotechnical variants. In the absence of selection, a population will just diffuse in form according to its internally generated rates of variation. Complex, well adapted sociotechnical constructions are not possible without some selection; sociotechnical adaptationist argue in particular that individual human genius and social selection is not sufficient to generate all the impressive sociotechnical structures that humans have created. Rather, economic and military competition have been essential drivers of technological progress, in the technical sense of the many trends described earlier

(stronger materials, higher buildings, faster transportation). The reason is that, while humans will often enough borrow technologies that seem beneficial, they also often exhibit resistance to novelty, or the leaders of particular cultures will be opposed to certain changes. Just as market competition ensures against grossly inefficient or complacent firms, economic and military competition more generally ensures against languid sociotechnical systems. This argument is central to Joel Mokyr's *The Lever of Riches*:

> The struggle for survival [in Europe] guaranteed that in the long run rulers could not afford to be hostile to changes that increased the economic power of their realm because of the real danger that an innovation or innovator would emigrate to benefit a rival. Technological improvements made abroad were pursued and imitated, foreign artisans were tempted and bribed to immigrate. Regimes that did not follow this course, such as Spain and the Ottoman Empire, fell behind and lost their economic and political power. Comparatively tolerant states, such as England and the Netherlands, became the cutting edge of economic progress and acquired political influence out of all proportion to the size of their populations. Competition between states stimulated innovative activity directly through government intervention…. The technological center of gravity of Europe moved over the centuries, residing at various times in Italy, southern Germany, the Netherlands, France, England, and again in Germany. Political fragmentation did not inhibit the flow of information from technological leaders to followers in Europe, and so it came to pass that the technology used in Europe always eventually settled on the best-practice technique in use regardless of where it had been invented.[175]

Jan Fagerberg points out how other eminent scholars of technology shared this emphasis on the mechanism of competition: "Schumpeter, extending an earlier line of argument dating back to Karl Marx, held technological competition … to be the driving force of … long run economic change."[176]

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175 Mokyr, Joel. 1990. *The Lever of Riches - Technological Creativity and Economic Progress*. Oxford: Oxford University Press, 206-207

176 Fagerberg, Jan, David Mowery, and Richard R. Nelson, eds. 2006. *Handbook of Innovation*. Oxford, UK.: Oxford University Press, 14-15, 18.

The Fatal Conceit

Humans have a tendency to infer intelligent design for functional structures. Prior to the Darwinian revolution, it was widely held—by scholars and laypersons—that only an intelligent being could have created the many complex adaptive forms of life on Earth. Evolutionary thinking has shown how processes of variation and selection can alone explain the emergence of the most complex functional entities, entities whose complexity and sophistication far exceeds the best efforts to date of humanity to understand them. Nobel Laureate Friedrich Hayek argued that complex social decision making, such as the allocation of productive resources, and complex social systems, such as "language, morals, law and money[,] are all the result of spontaneous growth and not of design…."[177] "The structures formed by traditional human practices are neither natural in the sense of being genetically determined, nor artificial in the sense of being the product of intelligent design, but the result of a process of winnowing or sifting, directed by the differential advantages gained by groups from practices adopted for some unknown and perhaps purely accidental reasons."[178] No group of planners could be capable of designing such an impressively functional system as our civilization: "if anything is certain it is that no person who was not already familiar with the market could have designed the economic order which is capable of maintaining the present numbers of mankind."[179]

Hayek thus argued that the belief that central planning could effectively build a complex social system or make complex social decisions was a "fatal conceit." This fatal conceit stemmed from ignorance about the evolutionary processes giving rise to cultural traditions; "tradition is not something constant but the product of *a process of*

177 Hayek. *Law, Legislation, and Liberty, volume 3: The Political Order of a Free People*, 163.
178 Ibid., 155.
179 Ibid. 163.

selection guided not by reason but by success…. There is certainly room for improvement [on our social systems], but we cannot redesign but only further evolve what we do not fully comprehend. "[180] The economic fate of centrally planned economies has lent much credence to Hayek's claims.

A further line of evidence—the issue of the timing of social innovation—supports the evolutionist's view of social systems. If humans are truly capable of effective design, [181] as rational choice economists often assume and social constructivists who don't mention (at least social) selectionist processes implicitly endorse,[182] then we should expect that major social innovations should all take place within a few human generations. And yet, "the basic tools of civilization," in Hayek's words, "language, morals, law and money," each emerged over hundreds, if not thousands of years of gradual change. The gradual emergence of these systems does not suggest rational design. Furthermore, most, if not all, 'users' of these technologies were oblivious to the causes of their functionality, just as the native speaker of a language does not understand the complexity of his own means of communication. Many technologies, such as the Japanese sword[183], were refined over hundreds of years to an impressive level of sophistication, and yet only now are the scientific reasons behind the success of these technologies becoming understood. To those who hold up human intelligence as the sufficient or primary cause of innovation, the question remains unanswered how the Japanese sword-smiths or linguistically

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180 Ibid.

[181] Does agency imply intelligent design? Yes. Agency is the extent to which an individual can cause an intentional change in a historical trajectory. To have agency is to have the capacity to intelligently "design" some aspect of the future.

[182] When social constructivists speak about the social shaping of technology, either this social shaping is intended or it is not. If it is intended, then the social constructivists are implying a degree of intelligent design. If the social influence is unintended, then we can code the causal process as a series of unintended consequences, and the system is deterministic (and possibly unpredictable).

183 Martin, Gerry. 2000. Stasis in Complex Artefacts. In *Technological Innovation as an Evolutionary Process*, edited by J. Ziman. Cambridge, UK: Cambridge University Press, 90-101

ignorant language entrepreneurs could possibly construct their technologies without a basic formal understanding. And besides, what took them so long?

Competition: the Missing Mechanism for Technological Determinism

Joel Mokyr argues that, "By and large, the forces opposing technological progress have been stronger than those striving for changes."[184] But, "as long as *some* societies remain creative, others will eventually be dragged along."[185] According to Mokyr, then, how is that the "stronger" social forces opposing technological progress have been so consistently and soundly defeated since the industrial revolution? Because while they are presumably proximally stronger, the social groups embracing technological change *become* stronger by virtue of their attitude towards technology. So long as *some* societies remain outside of the control of the *status quo*, all societies will eventually be "dragged along." Thus, in these quotes, and in many others, we find the missing mechanism for technological determinism. Competition compels all actors to adapt, even when the change is proximally resisted by most social groups. So long as some social group embraces change, an event most likely within an anarchic political system, than technological "progress" will persist.

Friedrich Hayek, like Joel Mokyr, sees technological progress largely in a positive light, but he also identifies how competition has restrained human agency, compelling many social groups to accept "progress":

> . . . it was the evolution of tradition which made civilization possible, [thus] spontaneous evolution is a necessary if not a sufficient condition of progress. And though it clearly produces also much that we did not foresee and do not like when we see it, it does bring to ever-increasing numbers what they have been mainly striving for. We often do not like it because the new possibilities always also bring a new discipline. Man has been civilized very much against his wishes. It was the price he had to pay for being able to raise a larger number of children.… The indispensable rules of the free society require

184 Mokyr. *The Lever of Riches - Technological Creativity and Economic Progress*, 16.
185 Ibid., 16, 302.

> from us much that is unpleasant, such as suffering competition from others, seeing others being richer than ourselves, etc., etc.[186]
>
> Man is not and never will be the master of his fate: his very reason always progresses by leading him into the unknown and unforeseen where he learns new things.[187]

Hayek here too argues that competitive processes have propelled the technological trends called by some "progress," while also identifying that this progress has come at a cost of increasing "discipline," "competition from others," inequality, and "much else that we did not foresee and do not like when we see it."

When we look back at the (pessimistic) technological determinists, we find that competitive processes are active in their narratives, though they did not highlight their significance. Winner, for example, suggests a general technological trend characterizing history which is implicitly adaptationist: "More highly developed, rational-artificial structures tend to overwhelm and replace less well-developed forms of life."[188]

In Ellul's writing we see that, while he emphasizes the "technical" as the proliferating dominant form of life, his underlying mechanism remains the proliferation of the adaptive (which in his case he believes to be always the "technical"):

> Nothing can compete with the technical means. The choice is made a priori. It is not in the power of the individual or the group to decide to follow some method other than the technical. The individual is in a dilemma: either he decides to safeguard his freedom of choice, chooses to use traditional, personal, moral, or empirical means, thereby entering into competition with a power against which there is no efficacious defense and before which he must suffer defeat; or he decides to accept technical necessity, in which case he will himself be the victor, but only by submitting irreparably to technical slavery. In effect he has no freedom of choice.

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186 Ibid., 168.
187 Ibid., 176.
188 Winner. *Autonomous Technology - Technics-out-of-Control as a Theme in Political Thought*, 212.

> We are today at the stage of historical evolution in which everything that is not technique is being eliminated. The challenge to a country, an individual, or a system is solely a technical challenge.[189]

Finally, Lewis Mumford hints at both economic and military competition as driving the trends that he describes. Merritt Roe Smith summarizes some of Mumford's claims:

> In the competition for world markets, industrial societies pressed hard to develop technological capacities that would give them an edge and, in the process, made the machine rather than the human condition the form against which all else was measured.[190]

In a section of Technics and Society, Mumford draws out the importance of military competition in the origins of industrial society:

> The state of paleotechnic society may be described, ideally, as one of wardom. Its typical organs, from mine to factory, from blast-furnace to slum, from slum to battlefield, were at the service of death. Competition: struggle for existence: domination and submission: extinction. With war at once the main stimulus, the underlying basis, and the direct destination of this society, the normal motives and reactions of human beings were narrowed down to the desire for domination and to the fear of annihilation—the fear of poverty, the fear of unemployment, the fear of losing class status, the fear of starvation, the fear of mutilation and death.[191]

On a more theoretical level, the question arises why competition necessarily, or at least has so consistently, selected for the trends described by the determinists, such as increasing population size, energy intensity, complexity, and so forth. At the most abstract level, we could restate this observation by saying that the adaptive topology—that is, the relationship between form and fitness—trended towards those characteristics. At a proximal level, we can look at the major processes of selection and explain, to a reasonable degree, why certain kinds of sociotechnical system have

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189 Ellul. Technological Order. Ellul. *The Technological Society*, 84.
190 Smith, and Marx, eds. *Does Technology Drive History? The Dilemma of Technological Determinism.*, 29.
191 Mumford. *Technics and Civilization*, 195.

proliferated. Thus, in a world where energy consumption has had large short term economic and military advantages, sociotechnical organisms would evolve to thoroughly exploit all energy sources, leading to historical deforestations in Europe, China and elsewhere, and the rapid burning of fossil fuels. In the case of energy sources where nearly the "full cost" is internalized by a single sociotechnical organism, such as traditional agriculture in Europe, sociotechnical organisms evolved to optimize more long-term returns, as with through the three-field system. Large armies tend to be beat smaller armies, though that trend has often been qualified by other parameters, such as training, armament, distance from home, access to resources, motivation, etc…

Trends have also been observed in biological evolution, though they are more controversial because they are mostly only trends "in the maximum," meaning that the maximum values of some metric have increased, with less clear changes in the rest of the distribution. For example, within the set of non-human living organisms, speed, geographical distribution, metabolic range, complexity, functional differentiation and specialization, cognitive capacity, sensory acuity and breadth have all increased in the maximum, over the long run. Over the short run, many of these trends have decreased. Paleontologist Daniel McShea has looked at the idea of directionality in evolution, and while the evidence is complex and the scholarly majority resistant to the idea, McShea and others present a solid case that there may be trends, and that these trends may be driven by a number of possible (passive and active) mechanisms. Ultimately, the question of the existence and mechanism behind evolutionary trends is an open empirical question, and has eluded theoretical understanding.

Perhaps, if we squint when observing long-term trends, as the loose abstract language of Ellul and Mumford and Winner allowed them to do, we can state simply that sociotechnical organisms become increasingly "technical" or "rational." If by

technical and rational we mean that which is adaptive for military and economic competition, then by definition, sociotechnical adaptation will trend towards increasingly "technical" forms. These technical forms may conflict with human instincts, such that modern society may feel "unnatural" and "unfair". Human instincts evolved in a certain evolutionary context, to solve certain kinds of problems, under a certain set of relatively egalitarian social configurations.[192] Since sociotechnical change will probably lead away from environments similar to our evolutionary origin, it is not a surprise that people will sometimes perceive our sociotechnical system to be "unnatural."

I don't believe that this interpretation does sufficient justice to the many technological trends. Why, for example, has the size of the largest organization unit (measured in terms of population of cells/people, energy input required, complexity, numbers and extent of non-kin relationships), and in sociotechnical evolution, the mean organization unit, continued to increase? Why do large armies, more times than not, beat small armies, and large empires beat small, large firms beat small? This isn't to say that large always beats small, only that trends can be observed in the maximum, and probably also the mean, towards larger size. Put differently, economies of scale and scope seem to be common in many sectors. Empires, armies, and firms rise and fall; but subsequent empires, armies and firms *tend* to be larger and more complex than the previous. Why? As yet, we have no reasons to infer the increasing adaptiveness of large, complex, energy intensive, forms from the laws of physics or biology. The problem is an empirical one, especially relevant to sociotechnical evolution: Why, on Earth, have complex (name-your-preferred-trend) sociotechnical organisms tended to proliferate at the expense of their rivals?

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[192] Wilson, David Sloan. 2003. *Darwin's Cathedral: Evolution, Religion, and the Nature of Society*. Chicago: University of Chicago Press, 21, 36.

Criticisms of Sociotechnical Adaptationism

A fundamental criticism about selectionist theories is that they are tautological. In simple terms, selectionist theories state something like: that which was good at proliferating proliferated; or that which is abundant today MUST have been good at proliferating by virtue of its abundance today. This criticism is appropriate to the extent that adaptationists 1) fail to acknowledge the constraints on variation and 2) naively postulate selection pressures without independent evidence.

"Adaptationism" in evolutionary biology is used to refer critically to those evolutionists who naively assume that every trait and organism must be adaptive. This intellectual tendency is also sometimes called "adaptationist storytelling" because it contorts any history into the adaptationist "just-so" narrative framework. In contrast to adaptationism, some scholarly work that is attentive to selection pressures emphasizes the "internal" constraints on variation that limit the extent to which organisms (or other entities) can adapt to selection pressures. Analyses that emphasize the internal constraints on variation tend to be more path-dependent, since the internal constraints are a product of past events and adaptations. In the evolutionary biology literature, this criticism is most famously expressed by Stephen Jay Gould and Richard Lewontin[193], who note that traits can also arise because of structural constraints that locked in during earlier evolution, optimization trade-offs between different selection pressures, random drift in small populations, and transmission bias (or adaptation for lower levels of selection). Adaptationists, they argue, will often apply a low burden

193 Gould, Stephen Jay, and R. C. Lewontin. 1979. The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Paradigm. *Proceedings of the Royal Society of London*

of proof for adaptationist claims, as well as conflate current function with its historical reason for proliferating.

While this critique is a welcome reminder of the dangers of excessive emphasis on selection pressures, it does not challenge the usefulness of the core adaptationist assumption (that most traits exist because they were—and often still are—adaptive). In the following section about sociotechnical evolution, a balanced, unified theoretical enterprise will be outlined in which the main criticisms of extreme adaptationism (and of naïve technological determinism) will be integrated, while maintaining their theoretical virtues of these approaches. Sociotechnical evolutionism balances the crucial insights from an emphasis on dominant selection pressures and adaptation, while still allowing for attention to historical path dependency, contingency, and countervailing selection pressures.

More generally, it should be said that the circular nature of adaptationism does not render it useless, so long as each side of the equation can be operationalized independently of the other, thereby opening up rich theoretical and empirical questions and insights. For example, 1) an adaptationist would hypothesize that under intense competition, most actors within the system will be motivated and designed to win (because those who were not, are no longer present). Thus, it is reasonable to infer that Olympians, having gone through many rounds of competition, will be highly motivated and trained to win. If the adaptationist hypothesis is false, such a scholar would know to look for either constraints on the variation of behavior or on other, more subtle selection pressures. Thus, if we found that some or most Olympians were not motivated or not maximally fit to compete in their sports, we would then ask if perhaps humans have some constraint on their possible variation (no matter how many rounds of selection, no human will be able to fly the 100m), or whether perhaps there

are other sources of selection (such as drug tests selecting against the drug-enhanced variant of Olympian).

Lastly, it should be stated that most fruitful paradigms themselves reduce to some form of tautology, for example, Newton's famous relationship between force, mass and acceleration: F=M*A.[194] Ultimately, this equation is a tautology, since mass cannot be defined independently of its ability to resist acceleration, nor can force be defined without the concept of acceleration. And yet, this equation is still fruitful: if I see something "massive" accelerate quickly it is fair for me to infer that much force was applied to it (which requires much energy) or that it was in fact less massive than I assumed, a Styrofoam car perhaps? A tautology should be judged by whether it yields new questions and insights. Likewise, since with evolutionary theory the selection pressures and character of variation can be operationalized independently of the evolutionary outcome, evolutionary theory can a be a fruitful semi-tautology.

Other critics of adaptationism offer counter-examples to refute an adaptationists' claim. While counter-examples are helpful empirical challenges to an adaptationist claim, they are rarely in and of themselves sufficient evidence to undermine an adaptationist claim for two reasons: 1) evolution is complex; an adaptationist claim offers a "first-order" approximate explanation of historical causality, and 2) evolutionism and adaptationism are statistical claims. Evolution, be it biological or sociotechnical, is a very complex process; just because the rainforest is full of millions of species (many undiscovered) living through complex and changing ecologies that researchers barely understand, does not mean that adaptationist approaches have been unproductive. Sociotechnical adaptationism offers a first

[194] Credit to Kauffman for this example: Kauffman, Stuart. 2000. *Investigations*. Oxford: Oxford University Press, 52.

approximation for long-term causal processes, one that is especially appropriate in contexts of extensive and intense competition.

Furthermore, many critics will attack a simplistic strawman version of adaptationism (possibly for good reason), but this, again, does not undermine the broader enterprise. For example, a sociotechnical adaptationist may claim that states with more powerful militaries have proliferated over time. But, a critic might argue, the war in Vietnam demonstrated how a more powerful military could lose (or at least stalemate) against a weaker military; the adaptationist response would point out that, while military power is often best measured using the typical metrics of man-power, level of technology, access to resources, economic support, and so forth, these all depend on the context; guerilla warfare is just such a context where military adaptations of imperial powers do not extend into new environments. This counter-example, then, requires added nuance from the adaptationists' operationalization of the concept of military adaptiveness, but would only undermine the adaptationist enterprise if the selection environment was so variable that the traits of the organism had no consistent relationship to its proliferation.

Likewise, adaptationism offers a statistical claim, which means that individual counter-examples are possible and sometimes common. To take another example from biological evolution, biological evolutionists have noted that if a new gene yields a fitness advantage of only around 1% (an organism with this gene will have approximately 0.01 more offspring), then after a 500 hundred generations the gene will be present in almost all organisms.[195] Thus, if there has been sufficient time (hundreds of selection events), then even very minor probabilistic selective advantages will predictably proliferate. That a critic could point out some counter-examples (in

195 For example, after 500 generations only 0.5% of the organisms will not have this gene, assuming that selection scales linearly.

the above case, 100 counter examples for every 101 examples) does not undermine the strength of the adaptationist argument, so long as the time frame and/or selection pressures are sufficient. In most cases the selective advantage will be more substantial (say 30%), and the time frame more reasonable (around 20 selection events). A sufficient span of time (and space), because it covers more selection events, is a crucial parameter for strong adaptationist analysis.

Adaptationists who have kept their epistemological perspective know that their ultimate intellectual aim is to weigh the varying obduracy of different constraints on variation and varying strengths of different selection pressures so as to explain the full complexity of history, not by ignoring counter-examples but by using them as impetus for further theoretical nuance.

One last concern about adaptationism, and evolutionary theory more generally, especially when applied to social systems, is that it has dubious normative implications and political potential. In the early 20th century racists and imperialists in the United States and Europe employed "Social Darwinism" to further their political agendas, most notably by Hitler to justify genocide. More generally, the "survival of the fittest" has often been understood to justify an amoral, "every man for himself," attitude. These connotations and misunderstandings have done much to detract from the appeal of an evolutionary theory, but the concerns are misguided.

First, it should be noted that no scientific theory brings with it a single set of normative prescriptions. Instead, every descriptive and theoretical work can be interpreted in a number of ways to yield varying normative inferences. A theory of technology provides an understanding about how things work, not how they *should* work. While it is possible that some theories about technology may have political implications, such as the concern that technological determinism discourages political

action, these consequences do not follow simply from the theory but from the context in which the theory is developed, employed and understood. As argued above, technological determinism can also be seen as politically empowering vis-à-vis social constructivism because it gives political activists warrant to push for radical, rather than reformist, change. Environmental and labor activists often invoke deterministic claims because it gives them greater justification for their large demands and because many of them truly believe that reformist measures will be insufficient against the forces of capitalism.

The normative implications of the interpretive flexibility of theory can be grasped by a cursory summary of the major ideological justifications for imperialism. The subjugation of neighbors has been justified because of the responsibility to spread the Gospel (and every other religion), political order, "peace," the free market, security, and in our own time, "freedom and democracy." That the Ten Commandments, and more amazingly, Jesus Christ's sermons of love and forgiveness, have been distorted in the ideological crafting of justification for war by "Christian" powers suggests that any belief system, no matter how benevolent, can be misused by political opportunists. Bruno Latour, in a typically provocative piece, has even argued that social constructivism may have gone too far in allowing itself to become ammunition for the neoconservative denial of global warming and other "liberal theories."[196] I think Latour exemplifies the best antidote to political misuse of intellectual scholarship: to speak out against its misuse, even if it may come at a personal cost. The political risk is greater if we censor entire research programs because of their possible ideological misuse, than if we encourage rigorous debate from a critical, responsible standpoint.

196 Latour, B. 2004. The Last Critique. *Harper's Magazine*, April, 2004

Richard Dawkins exemplifies how a scholar can intellectually advocate for a particular theory of how the world works, and politically advocate against the consequences of the process that this theory describes, a position that would be impossible or ineffective without a sufficient development of this theory. Dawkins prefers:

> . . . to agree that natural selection is the dominant force in biological evolution, admit its unpleasantness, and fight against it as a human being. I hear [evolution's] bleak sermon as a call to arms[…] At the same time as I support Darwinism as a scientist, I am a passionate anti-Darwinian when it comes to politics and how we should conduct our human affairs.[197]

Likewise, it is possible to advocate for an evolutionary understanding of sociotechnical systems, while endorsing political programs that seek to control the very processes of economic and military competition that our scholarship seeks to understand. In fact, I believe that political action will be most effective when it is tied to a theory of sociotechnical evolution; neither extreme of naïve technological determinism nor radical social constructivism seem to me to be politically efficacious because of their neglect of, respectively, the possibility of political intervention and the obduracy of certain technological trends. To intervene effectively one must understand what processes are driving change, and how, and thus what actions will be most likely to divert the trajectory of sociotechnical systems in a way favorable to one's values. Agency is not just the absence of determinism (obdurate historical trajectories), but the possibility to perturb the historical trajectory in a predictable way. This can only be achieved by mapping the mechanisms that give rise to deterministic processes.

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197 Dawkins, R. (2003). A Devil's Chaplain: Reflections on Hope, Lies, Science, and Love, Houghton Mifflin Co, 10.

Sociotechnical Evolution: Unifying Social Science

A unified theory of sociotechnical evolution begins with the belief that most scholarly approaches to sociotechnical systems have some insight to offer, and that most disagreement among approaches arises because of the different premises of the various approaches. These different premises, however, can be thought of as parameters that vary across historical contexts, such that each scholarly approach is appropriate in some contexts. In this section I lay out the most important parametric differences in these approaches, so as to create a theoretical space where these different approaches can speak to each other, ultimately with the aim of constructing a meta-approach for studying technology. The critical component to this task was a specification of the mechanism that could give rise to the claims of the technological determinists. Having shown how the most deterministic claims could emerge from a mild constructivist ontology through selectionist processes, the theoretical bounds of sociotechnical evolution can be drawn. Within its circumference are most approaches to technology, with the absence of the irreconcilable extrema, which in our case includes radical social constructivist and naïve technological determinist claims. A selectionist or evolutionary theoretical unification in the study of technology has many advocates[198], and even more in the study of social systems from other disciplines.[199]

198 Advocates for explicitly selectionist theories in the study of technology include, among others: Boyd, Robert, and Peter J. Richerson. 2005. *The Origin and Evolution of Cultures*. New York: Oxford University Press;Geels, Frank W. 2005. *Technological Transitions and System Innovations*. Cheltenham, UK: Edward Elgar Publishing;Mokyr. *The Lever of Riches - Technological Creativity and Economic Progress*;Mokyr, Joel. 2002. *The Gifts of Athena: Historical Origins of the Knowledge Economy*. Princeton, NJ: Princeton University Press;Murmann, Johann Peter. 2003. *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions*. Cambridge, UK: Cambridge University Press;Nelson, Richard R. 1995. Recent Evolutionary Theorizing About Economic Change. *Journal of Economic Literature* 33 (1):48-90;Nelson, Richard R., and Sidney G. Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, Mass.: Belknap Press of Harvard University Press;Nelson, Richard R., and Sidney G. Winter. 2002. Evolutionary Theorizing in Economics. *Journal of Economic Perspectives* 16 (2):23-46;O'Connell, J. 1992. The Fine-Tuning of a

I begin this synthesis by laying out the major theoretical approaches to technology, as systematized in Figure 3 in descending order from most deterministic and most macro (Dark background) to the least deterministic and most micro (White

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Golden Ear - High-End Audio and the Evolutionary Model of Technology. *Technology and Culture* 33 (1):1-37;Vincenti, Walter G. 1990b. *What Engineers Know and How They Know It - Anylitical Studies from Aeronautical History*. Edited by M. R. Smith and T. P. Hughes, *Johns Hopkins Studies in the History of Technology*. Baltimore: Johns Hopkins University Press;Ziman, John, ed. 2000. *Technological Innovation as an Evolutionary Process*. Cambridge, UK: Cambridge University Press.

199 Other advocates of an evolutionary theory of society, to offer a random sample from other disciplines such as political science, philosophy, sociology, linguistics, and ecology, include: Aunger, R. 2000. *Darwinizing Culture: the Status of Memetics as a Science*. Oxford, UK: Oxford University Press;Blackmore, Susan J. 2000. *The Meme Machine*. Oxford, UK: Oxford University Press;Campbell, Donald T. 1982. Evolutionary Epistemology. In *Learning, Development, and Culture: Essays in Evolutionary Epistemology*, edited by H. C. Plotkin. New York: John Wiley & Sons;Carneiro, Robert L. 1992. The Role of Natural Selection in the Evolution of Culture. *Cultural Dynamics* 5:113-140;Cziko, Gary. 2001. Universal Selection Theory. In *Selection Theory and Social Construction - The Evolutionary Naturalistic Epistemology of Donald T. Campbell*, edited by C. Heyes and D. L. Hull. Albany: State University of New York Press;Dennett, Daniel C. 1995. *Darwin's Dangerous Idea: Evolution and the Meaning of Life*. New York: Touchstone;Giere, Ronald N. 2001. Critical Hypothetical Evolutionary Naturalism. In *Selection Theory and Social Construction - The Evolutionary Naturalistic Epistemology of Donald T. Campbell*, edited by C. Heyes and D. L. Hull. Albany: State University of New York Press;Gintis, Herbert. 2000. *Game Theory Evolving*: Princeton University Press;Grantham, T. A. 2000. Evolutionary epistemology, social epistemology, and the demic structure of science. *Biology & Philosophy* 15 (3):443-463;Hayek. *Law, Legislation, and Liberty, volume 3: The Political Order of a Free People*;Henrich, J., and Francisco Gil-White. 2001. The Evolution of Prestige. *Evolution and Human Behavior* 22 (3):165-196;Henrich, J., and R. McElreath. 2003. The evolution of cultural evolution. *Evolutionary Anthropology* 12 (3):123-135;Hodgson, G. M. 1996. An Evolutionary Theory of Long-Term Economic Growth. *International Studies Quarterly - Special Issue: Evolutionary Paradigms in the Social Sciences* 40 (3);Hull, David L., ed. 2001. *Science and Selection: Essays on Biological Evolution and the Philosophy of Science*. Cambridge, UK: Cambridge University Press;Kauffman, Stuart. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. New York: Oxford University Press;Kauffman, Stuart. 1995. *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. Oxford: Oxford University Press;Knudsen, Thorbjorn. 2003. A neo-Darwinian model of science. In *The Evolution of Scientific Knowledge*, edited by H. S. Jensen, L. M. Richter and M. T. Vendelo. Cheltenham, UK: Edward Elgar;Linares, O. F. 2002. Cultural evolution: Contemporary viewpoints. *Cambridge Archaeological Journal* 12 (2):277-279;McNeill, William H. 2001. Passing Strange: The Convergence of Evolutionary Science with Scientific History. *History and Theory* 40:1-15;Sanderson, Stephen K. 1997. Evolutionism and its Critics. *Journal of World-Systems Research* 3 (1):94-114;Sanderson, Stephen K. 2001. *The Evolution of Human Sociality - A Darwinian Conflict Perspective*. Oxford: Rowman & Littlefield Publishers;Spruyt. *The Sovereign State and Its Competitors*;Thompson, William R, ed. 2001. *Evolutionary Interpretations of World Politics*. New York: Routledge;Trigger. *Sociocultural Evolution*;Wilson, D. S., and E. Sober. 1994. Re-introducing Group Selection to the Human Behavioural Sciences. *Behavioral and Brain Sciences* 17 (4):585-654;Wilson. *Darwin's Cathedral: Evolution, Religion, and the Nature of Society*.

background).[200] This typology could be modified and expanded in various ways, for example, to include various other schools of thought which have been neglected in this paper, such as that of Weberian socio-economics and specific schools within political science. Appendix A offers a more complete table, from which the following is based.

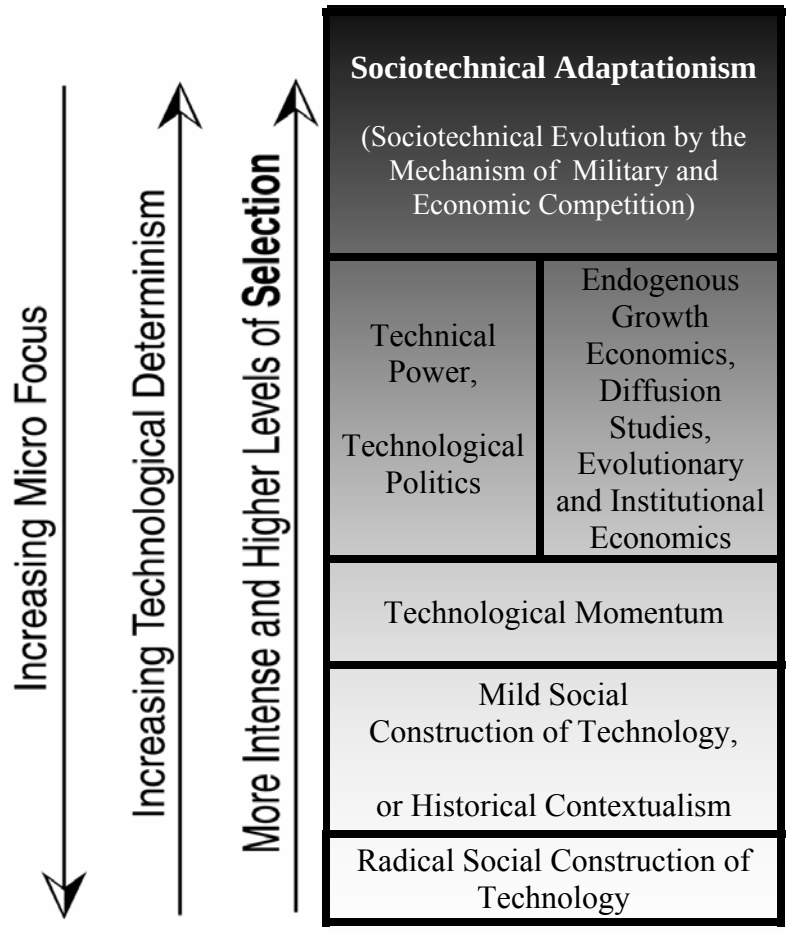

Figure 3 - School's of Thought in the Study of Technology (Macro Determinism = High Selection)

Figure 3 is an expanded form of Figure 2. I have included some economic approaches, including Endogenous Growth Economics, Diffusion Studies, and

200 Again, credit to Thomas Misa for his insight on the correlation between scale of analysis and propensity to determinism.

Evolutionary and Institutional Economics. Endogenous Growth Economics builds off of neoclassical growth economics by *endogenizing* the rate of technological progress.[201] Diffusion Studies explores why innovations diffuse (or fail to) through a population.[202] Evolutionary and Institutional Economics appreciate that actors are not perfectly rational, information is not perfect, and that firms and markets are situated within political institutions and social norms; these strands of economics allow for much more path-dependency.

I have also included in Figure 3 the missing mechanism leading to deterministic outcomes: military and economic competition. Figure 3 illustrates how as the scale of analysis increases, the tendency to determinism increases *because* the intensity of military and economic competition increases. That is, over larger scales of analysis there will 1) be more instances of economic and military competition, and 2) cultural forces will be less coherent and collective action more costly, further exacerbating the "deterministic" selection for economically and militarily adaptive traits.

The different levels of selection can be listed as follows. From the lowest levels to the highest, we have cognitive/behavioral selection, social selection, economic selection, military selection, and then ecological selection. I will discuss these levels of selection in more detail later, suffice it for to note that under this typology, social selection is below economic and military selection. Thus, over larger scales of analysis we tend to observe more the effects of higher levels of selection, such as, for the purposes of this paper, military and economic selection.

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[201] See, for example, Romer, Paul M. 1990. Endogenous Technological Change. *Journal of Political Economy* 98 (5):S71-S102;
Grossman, Gene, and Elhanan Helpman. 1991. *Innovation and Growth in the Global Economy*. Cambridge, MA: MIT Press;
Aghion, Philippe, and Peter Howitt. 1998. *Endogenous Growth Theory*. Cambridge, MA: MIT Press
[202] Rogers, Everett M. 1995. *Diffusion of Innovations*. New York: The Free Press.

Path-Dependency of Variation

There is a second axis on which we can lay out the various approaches to technology, and that is on the path-dependency of variation. Evolutionary theory, and the study of living systems more generally, tend to offer two kinds of explanations, the mechanistic and the functionalist, also called proximal and ultimate explanations. Proximal/mechanistic explanations are those that trace forward, "normal" causality, and explain the rise of new *variation*. Ultimate, functionalist explanations explain the characteristics of an organism[203] by the functions that they serve, and thus describe the character of *selection*. To take the classic example in evolutionary biology: plants tend to grow towards the light. They do this because A) some cells in a plant have a particular configuration that makes them phototropic, and/or B) the function of growing towards the light was adaptive for most plants. Ultimate, functionalist explanations have also been labeled "downward" causation because the form of the higher level interactor causes the configuration of lower level entities; as in the example, the functional requirements of the plant (higher level interactor) causes the configuration of the cells within the plant (lower level). Just as we could arrange

[203] The term organism is readily understood, but philosophically ambiguous. Theoretically speaking, an evolutionary system consists of 1) replicators, which are the basic unit of information transmission, such as the gene in biological evolution, and 2) interactors, which are the functional expression of a group of replicators on which selection is acting, such as the individual creature. In socio-technical evolution the concept of the replicator is not as immediately useful as in genetic evolution, though technically there must be some lowest entity that carries adaptive information. Note also that there are often overlapping or encompassing interactors; the interactor is the relevant "phenotype", which depends on the selection environment. For example, a gene may proliferate based on 1) intra-organismic competition such as meiotic drive, 2) the proliferation of individual organisms, 3) the proliferation of groups of individuals (kin or non-kin), through for example the evolution of cooperation. The interactor for a gene, then, could be the gene, the individual organism, a group of organisms, or even the species or clade (group of related species), depending on the selection context. In David Hull's words, the interactor is, "that entity for whom its characteristics will most directly determine the proliferation rate (of its replicators)."

different theories of technology according to the character of selection (see Figure 3), so we can arrange different theories of technology according to the character of variation.

For our purposes, the most important characteristic of proximal/mechanistic variation is the extent to which it is path-dependent. If variation is not path-dependent, then selection pressures will move a population towards the most adaptive forms possible. However, if variation is path-dependent, then the particular course of an evolutionary system will determine what future variants are possible. Thus, in systems with path-dependent variation, analyses that pay more attention to history will be more plausible. The richness of evolutionary theory is that, depending on the character of variation and selection in a particular evolutionary system, it allows for a balance between contingency and inevitability, or paraphrasing the title of Mokyr's fortcoming book, between "Chance and Necessity."[204]

In the following pages I describe how different theories of technology could be situated in terms of the two parameters of 1) the level and intensity of selection, and 2) the path-dependency of variation. I will introduce the full figure in parts, because the final figure is quite dense. I hope that working through these figures will be a productive way of conveying a set of ideas because it will allow for a methodical discussion and will yield a single graphical representation of what could otherwise be a daunting theoretical apparatus.

[204] Mokyr, Joel. forthcoming. *Neither Chance nor Necessity: Evolutionary Models in Economics and History*.

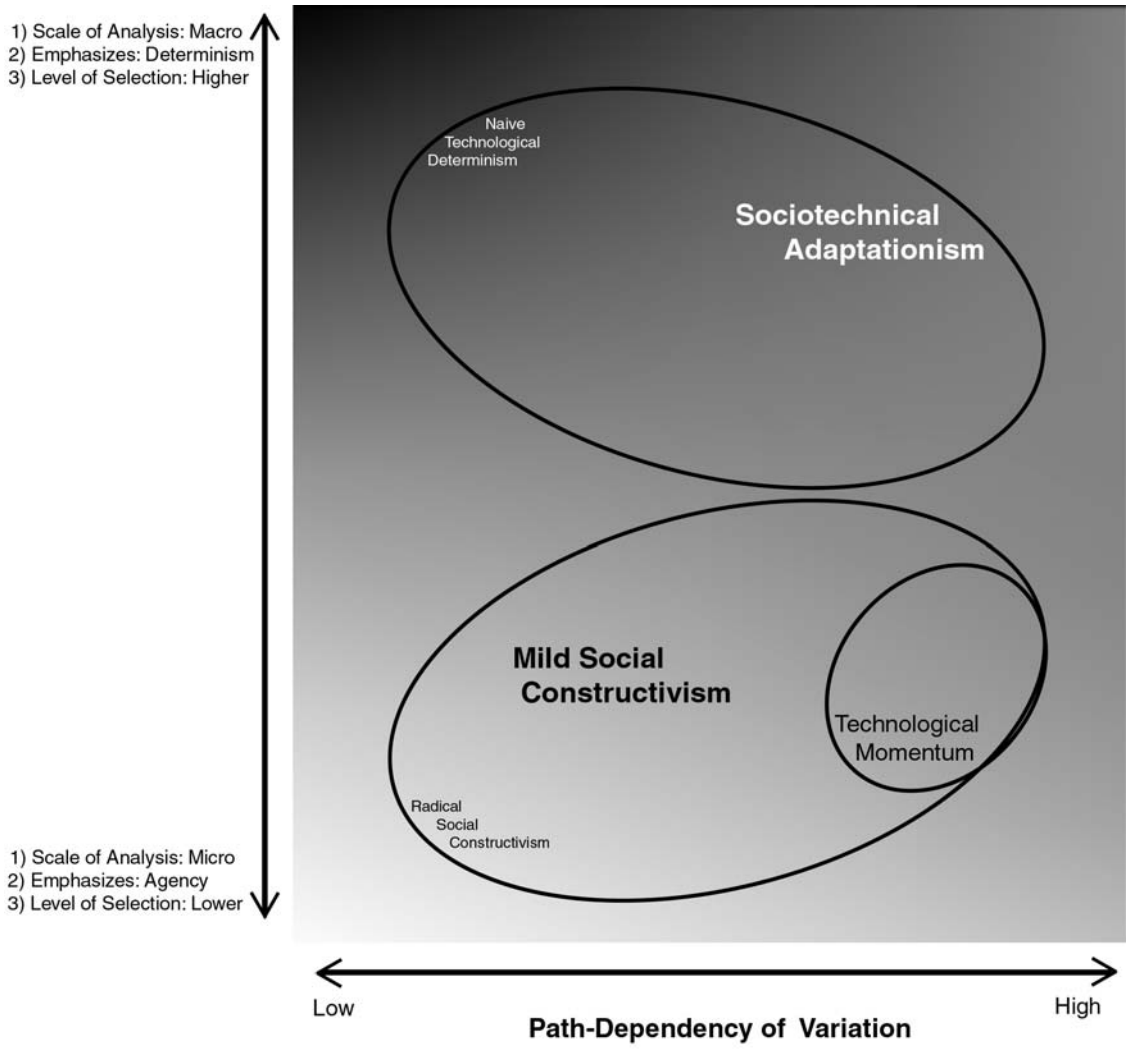

Figure 4 - Theories of Technology by Variation and Selection

In Figure 4 we have the two principal axes. On the y-axis we actually have three axes which correlate: 1) the scale of analysis; 2) the degree of determinism; 3) the level of selection. That is, as we go "up" the y-axis we increase our scale of analysis, which tends to yield more deterministic scholarship (as Misa noted), and we tend to observe more instances of higher level selection, such as military and economic competition. On the x-axis we have the degree of path-dependency in variation.

Radical Social Constructivism exists in the bottom left corner, where military and economic selection do not exist, and actors have (seemingly) unlimited variation. Mild Social Constructivism occupies a broad space in which military and economic selection pressures are weak at most, and extends across most of the range of possible path-dependency in variation. Mild Social Constructivist scholarship looks in a detailed way at historical particulars and contingencies. Theories of technological momentum, by introducing the constraints that past actions have on present behavior but still avoiding central attention to selection pressures, is situated in the bottom right. Thomas Hughes was correct to claim that his theory held a middle ground between radical constructivism and technological determinism, as possible variation is limited by the actions of the past. Hughes' writing does also occasionally employ economic selectionist processes, though he does not foreground such processes in his writing.

Sociotechnical adaptationism covers those theories that emphasize higher levels of selection (such as economic, military, and occasionally ecological), and covers, like mild constructivism, the whole range of possible path-dependency in variation. Sociotechnical Adaptationism emphasizes the selectionist convergence of a diverse population towards an adaptive equilibrium. In the top-left corner we have those arguments that I've labeled as Naïve Technological Determinism. There is no simple distinction between Naïve Technological Determinism and more acceptable types of Technological Determinism and Sociotechnical Adaptationism, though probably the most important distinction is whether the analyst takes seriously the problem of providing a mechanism for the observed deterministic trends. Scholarship, like much of Ellul's, that frequently naively posits causal power to technological trends belong in this category.

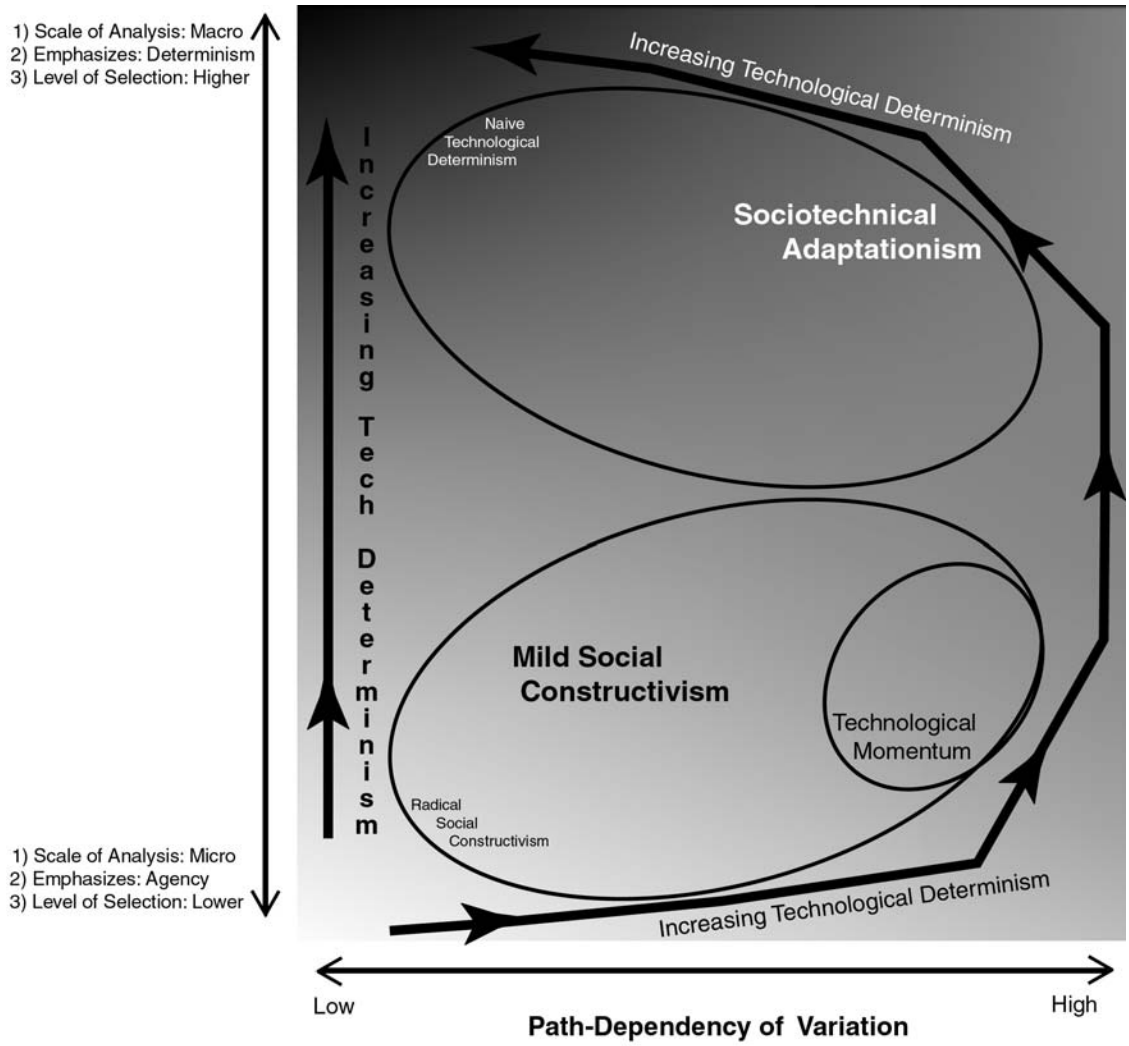

Figure 5 - Theories of Technology with Gradient of Increasing Technological Determinism

In Figure 5 I have added two arrows to help illustrate how technological determinism increases along this two-dimensional typology. In the bottom left, where the background grey is lightest, we have those theories of technology that assign the most agency. In the top left corner, where the background grey is darkest, we have those theories of technology that are the most deterministic. As we move up the figure and up the levels of selection, we find more deterministic theories of technology.

Interestingly, though, as we increase the path-dependency on variation we have a more complex relationship with agency. Starting in the bottom left, as we add

momentum we have increasing determinism, as Thomas Hughes and Wiebe Bijker point out. Technological systems carry the intentions of the past and structure the present. Under higher selection (the top of the figure) as we increase the path-dependency of variation we actually get more agency. If variation is not path-dependent, then under intense high levels of selection entities will evolve to the most adaptive state possible. With path-dependent variation, though, there will be critical moments in history where small changes could perturb the system into a different long-term outcome. Imagine a technological system with returns to scale; whomever first initiates the system will have an opportunity to set various standards and configurations that will become more costly to change as the system grows. Thus, if there is path-dependent variation, system builders and other actors at critical moments in history will have agency even under intense high levels of selection. In future figures I will not include the arrows, though the grey-background gradient can serve as a reminder of the relationship between the two axes and agency.

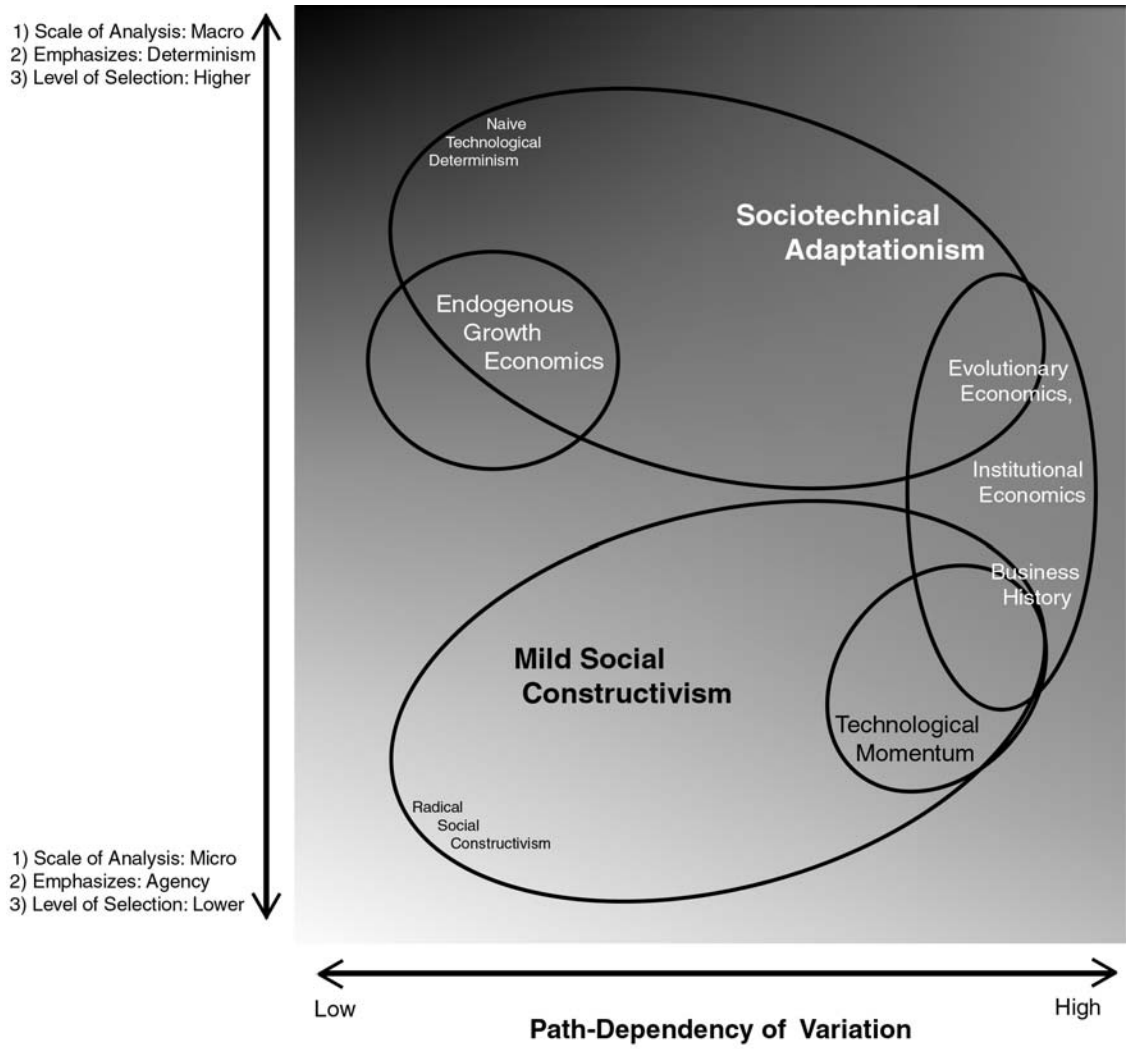

Figure 6 - (Economic) Theories of Technology by Variation and Selection

In Figure 6 I have added some economic schools of thought. On the left we have Endogenous Growth Theory and other economic approaches that believe that "the pace and direction of industrial innovation" responds to the "expected profitability of inventive activity,"[205] and seek "general-equilibrium" solutions that correspond with their data-sets. General equilibrium solutions are only possible in systems without returns to scale and thus without path-dependence. Furthermore,

[205] Grossman summarizing Schmookler approvingly: Grossman, and Helpman. *Innovation and Growth in the Global Economy*, 5.

endogenous growth theories tend to posit actors who are capable of a breadth of action as they are usually blessed by perfect rationally, complete markets, and costless transactions. Endogenous Growth Economics, except in the cases where the population is small, tend to equilibrium outcomes where the selection environment (market competition) is the determinant of the historical trajectory.

On the right hand side, stretching across different levels of section and scales of analysis, we have, from top to bottom, evolutionary economics, institutional economics, and business history. We could also add diffusion studies towards the top of this oval. These economic approaches all emphasize history in the inertial construction of complex social systems, though they to increasing degrees also emphasize economic selection as a central process in their explanations.

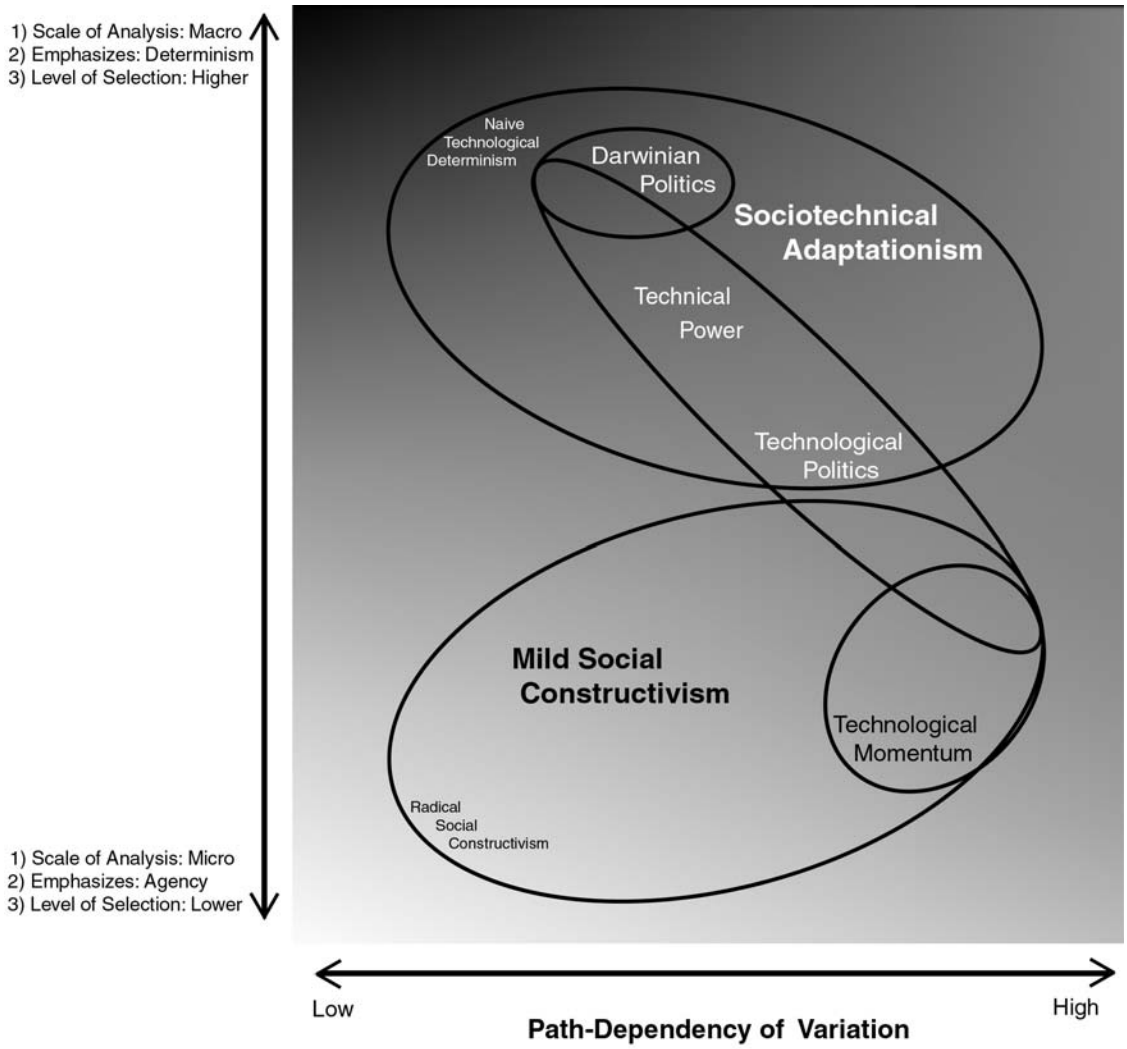

Figure 7 - (Political) Theories of Technology by Variation and Selection

In Figure 7 I have added some approaches to studying technology that emphasize political or military power. These approaches begin in the bottom right, near Technological Momentum, where power is passively expressed through the structures of the past. Under theories with Technological Momentum, the past has some power over the present, though the political dynamic of the present is underspecified. These approaches, what I've called "Technological Politics", believe that artifacts (and systems) can have politics built into them, and thus that technological creation is political. The source of power and politics under these

approaches, though, is always previous political groups. Technologies are not "born" with their own politics.

As we follow this oval up to the left, this category merges with what I've called "Technical Power", which is those schools that believe that certain technologies do not just have politics built into them, but actually have their own politics: that certain kinds of technologies are politically valenced. Winner's claim that nuclear technology is valenced towards authoritarian regimes and Mumford's view that some technologies are democratic while others are authoritarian are an examples of this. This category slopes up and to the left because as technologies themselves are "born" with their own politics, the past politics that have been built into structures becomes less and less important.

The top-left of this category merges with what I'm calling Darwinian politics which includes those military and political historians who argue that the emergence of superior technologies led to the proliferation and domination of whatever groups happened to possess those technologies. Thus, Darwinian politics might include Kenneth Pomeranz's argument that England came to dominate the world because it happened to have sufficient density of and proximity to coal to initiate the industrial revolution.[206] Or we might include Philip Hoffman's argument that Europe had a comparative advantage in violence due to its superior "market" for military goods and ideas.[207] In Darwinian Politics the technologies of the dominant actors matter more than any other of their characteristics, and it's always just a matter of time before some other power imitates, innovates and surpasses the dominant state. This category is similar to Realism within political science, where states behave maximally

[206] Pomeranz. *The Great Divergence: China, Europe, and the Making of the Modern World Economy.*
[207] Hoffman, PT. 2005. Why Is It That Europeans Ended Up Conquering the Rest of the Globe? Prices, the Military Revolution, and Western Europe's Comparative Advantage in Violence.

rationally so as to perpetuate their power amidst a ruthless inter-state competition for survival. In Realist theories, adaptive new sociotechnical configurations alter the balance of power, to the detriment of those systems which cannot adapt.

Finally, in order to complete this stage of the figure, I've drawn a thick white border which demarcates the breadth of scholarship that can (or should be able to) speak to each other within a theory of sociotechnical evolution, so long as the scholars recognize that their theoretical strengths are most appropriate under their particular parameters of selection and variation.

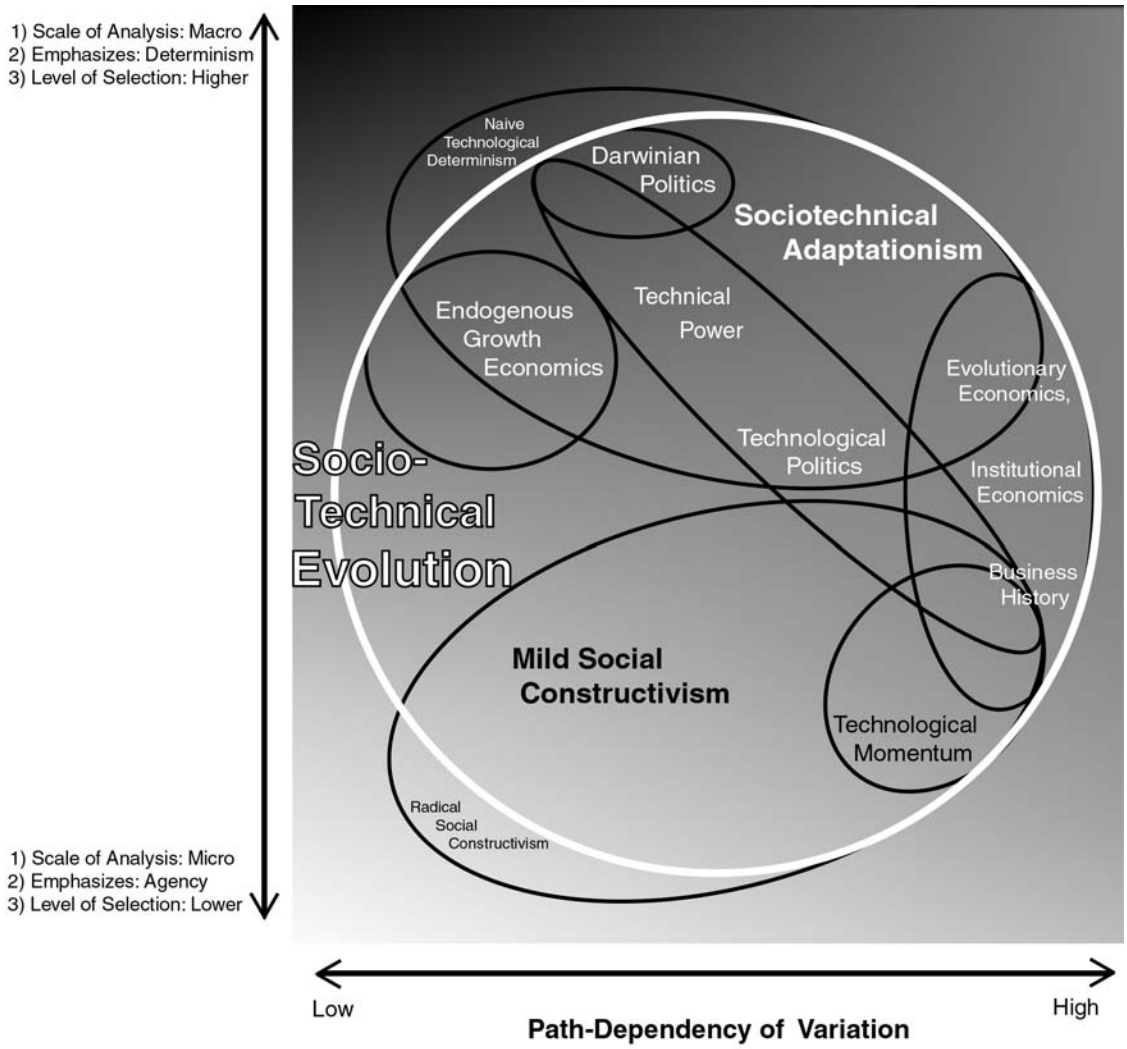

Figure 8 - Sociotechnical Evolution

The main claim at this point is that almost all approaches to technology can speak to each other, once their theoretical context of variation and selection is appreciated, except the extremes within constructivism and adaptationism, respectively: radical social constructivism and naïve technological determinism.

Levels of Selection/Scales of Analysis

The final theoretical insight required to unify the study of technology involves an appreciation of the ubiquity of selectionist processes (even in mild constructivist contexts), and the different kinds (or levels) of selectionist processes. That is,

processes of differential proliferation are operative under all contexts of analysis, though the processes are different and they select for different traits.

Darwin introduced at least three kinds of selection: natural, artificial and sexual. These different kinds of selection are not discrete, but they are distinguishable. The adverb preceding "selection" is meant to indicate the kinds of processes that are "selecting" the different rates of proliferation. Darwin used artificial selection to refer to selection processes guided by humans, such as selective breeding. Natural selection referred to all those "natural" processes that led to the differential proliferation of organismic variants. Sexual selection was a subset of natural selection, in which intra-species sexual behavior led to differential proliferation of some, often seemingly maladaptive, traits.

Likewise, it is productive to distinguish between different kinds of selection that operate on sociotechnical entities. These different *kinds* of selection—or processes of differential proliferation—have different consequences for the evolution of a sociotechnical entity. Once again, though, I will note that these different kinds of selection are not discrete: there are many processes that cannot be easily categorized into only one category. Nonetheless, the categorization of different kinds and levels of selection is productive, for reasons that will be made more clear during this section. In the following section I will descend the levels of selection, discussing ecological, military, economic, social, and cognitive/behavioral selection.

The reason different selection processes are often framed as "levels," with some above or below others, is because 1) some kinds of selection operate on longer ("higher") time scales, and 2) some selectionist processes are embedded within each other (in which case the "higher level" are those selectionist processes which are higher on the organization hierarchy and, again, tend to operate on longer time scales). Joel Mokyr, for example, argued that technological change in firms occurred through

embedded levels (or layers) of selection: the market selects firms, firms select design options, cognitive routines and personnel, and personnel select ideas from a broader scientific, technical or commercial community. If there are long-term trends in history we should look for them within the highest levels of selection, and only need to consider the lower levels to the extent that they affect the production of variants.

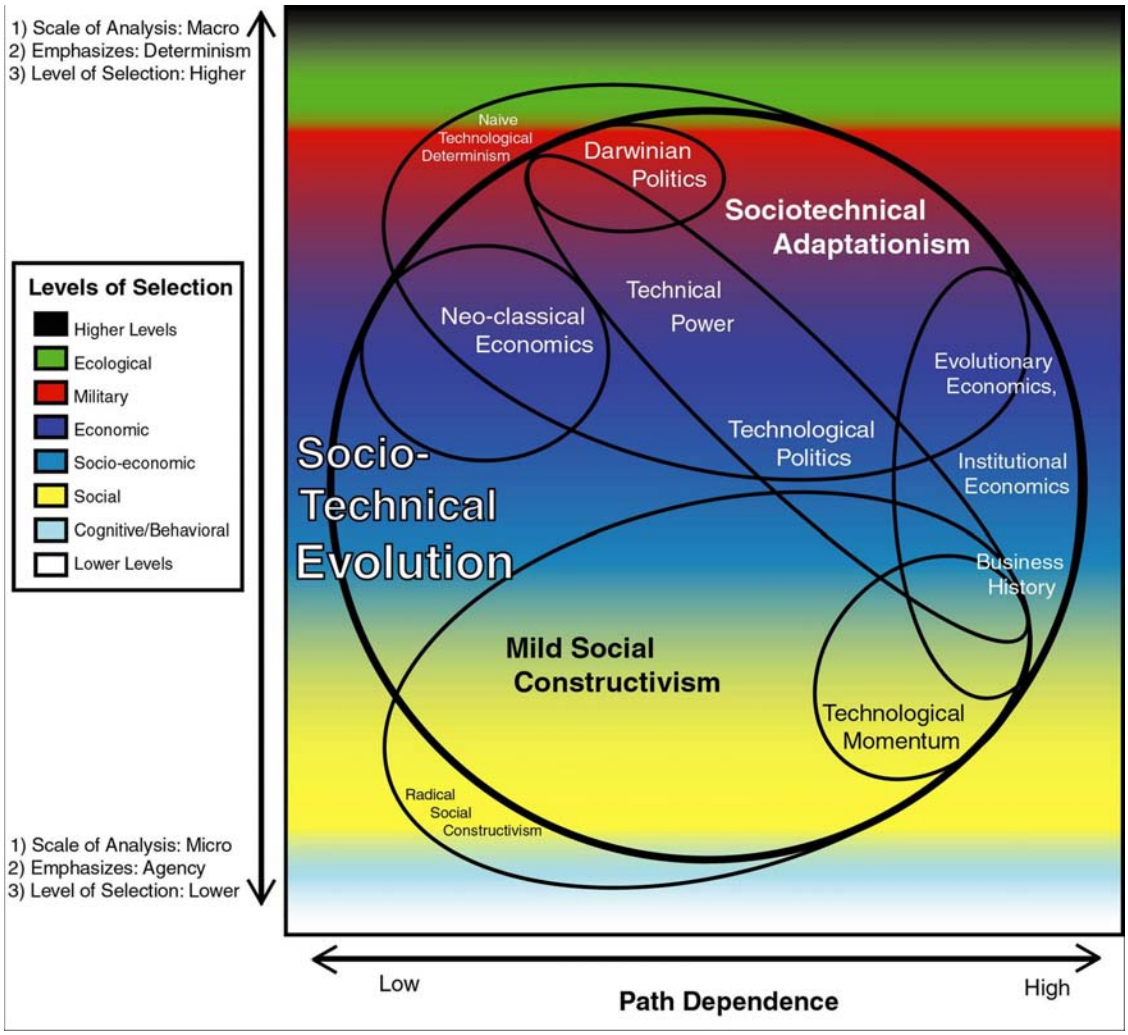

Figure 9 - Theories of Technology, Levels of Selection

Ecological Selection. Ultimately, all kinds of selection reduce to the differential proliferation (or survival) of the organism that possesses the trait under selection. To take the most extreme example, to illustrate the absolute limits of a theory of technology that neglects selectionist processes (such as radical social constructivism), imagine that a social group constructs an interpretation of a dagger as something that everyone should impale prior to sleep. This example is ridiculous, but it illustrates the point: a trait (such as an interpretation of a technology) that immediately kills its interactor (the entity possessing the trait) will itself not proliferate, *because* the trait will die with the interactor. We could create an infinite list of sociotechnical traits which are this maladaptive, though the list would be ridiculous (because no one "in their right mind" would ever adopt such a trait): the use of lethal amounts of cyanide as a mandatory cooking ingredient, the annual spread of salt onto agricultural fields right after harvest, the placement of dead creatures into the water supply, plugged-in toasters as bath toys, etc… Note that I am not arguing that it is maladaptive for components of interactors to die. Just as it could be adaptive for an ant colony for some soldiers to die in defense, so could it be adaptive for a culture to have some of its members die "for the cause". It would, however, be maladaptive if an interactor had *all* of its members (human and non-human) die "for the cause". In history we do have kinds of sociotechnical "suicide," but they tend to operate over much longer time scales, probably because humans are intelligent enough to modify behavior that leads to severe short-term consequences. Toynbee wrote that "Civilizations die from suicide, not by murder."[208] While the relative importance of self vs other inflicted civilizational death is up for dispute, that some civilizations have died from their own actions can not be disputed. Jared Diamond's recent book *Collapse* lists a few of

208 Aridan, Natan. 2006. Abba Eban, The Toynbee Heresy. *Israel Studies* 11 (1):91-107

these suicides, exploring "how societies choose to fail"[209] with examples including Easter Island, Norse Greenland, and the Maya. In these cases, the sociotechnical configurations of the respective societies interacted with the environment and itself in a self-destructive manner. Almost all sociotechnical traits within these societies died (or failed to proliferate) with the failure of these societies. From an evolutionary point of view, those traits that contributed to the sociotechnical suicide, such as the Easter Islander's excessive propensity to cut down trees to construct their impressive Moai and other artifacts, were *ecologically* maladaptive, and were selected against. There were other "linked" traits that died with these societies, but did not themselves cause the death; these traits are adaptively neutral because if they were part of another interactor they could have proliferated: they did not influence the interactor's ability to proliferate. Every sociotechnical system, or community of systems, must, in the final analysis, be able to extract from the environment the resources that it needs to survive. If not, that sociotechnical system will die, along with its traits. Those traits that prevent the largest interactor in which the trait resides from surviving—those that are ecologically maladaptive—will themselves fail to proliferate. More generally, those traits that hinder or encourage the ability of their larger interactor to proliferate will themselves proliferate less or more rapidly and extensively. The highest level of selection, the process of differential proliferation under which severely maldaptive traits will lead to the suicide of sociotechnical interactors, is ecological selection.

Processes of differential proliferation that we can label as exclusively "ecological" are rare in history; however, ecological processes are always important in determining the success or failure (rates of proliferation) of societies. There is thus messiness in the processes of selection; most of the time many different processes of

209 Diamond, Jared. 2005. *Collapse: How Societies Choose to Fail or Succeed*. New York: Penguin Group

selection change the rate of proliferation of (embedded) interactors, and at all times almost all processes are significant. Even in the ideal examples of ecological selection, such as the society on Easter Island, social processes were obviously at work. From a theoretical point of view, though, we can distinguish between the complex social processes of variation (proximal/mechanistic causation) which led to a certain kind of society, and the deterministic processes of selection (ultimate, functionalist causation) which are theoretically distinct from the social processes. In this model, variants *cause* selective effects; the effects emerge predictably from the ecological environment given the particular variant. Put simply, social processes decided what kind of society would exist, the ecosystem "decided" if that society would persist. The interactor was part social, the selection environment was not.

Military Selection. In biological evolution, one of the biggest priorities of any organism, right after being able to acquire the necessary inputs (food, water, heat), is to defend itself against predators. The same is true in history. Whether Toynbee was right about suicide being the leading cause of civilizational death, murder is an uncontested second. In the story of sociotechnical evolution, from the conquests of Alexander the Great, the Roman Empire, and Europe, to take just Western examples, sociotechnical configurations such as literacy, forms of government, and productive and military technologies have proliferated through military conquest. Any sociotechnical organism that could survive ecological selection had to, eventually, prepare for military selection. Many scholars have argued that military competition has been the driving process in the evolution of many sociotechnical entities, including the state itself.[210]

Again, what does it mean to say that military selection is independent of social processes? Certainly, the military is composed of social entities and is designed by social actors. This explains the *variation* in military forms. But why do different military forms proliferate? To a substantial extent there is imitation and other social processes that lead to the evolution and convergence of military forms.[211] But, there are times in history when different social groups refuse (or don't have the opportunity) to imitate their enemies; in those circumstances where both groups literally fight to the death, the determinant of which sociotechnical system survives depends on the relative strengths of the respective military configurations. When the ruthless gun-bearing Maori sailed to and attacked the non-violent Moriori on the Chatham Islands,[212] the

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210 Carneiro, Robert L. 1970. A Theory of the Origin of the State. *Science* 169:733-738;Spruyt. *The Sovereign State and Its Competitors*;Tilly. *Coercion, Capital, and European States, AD 990-1992*

211 Lynn, John A. 1996. The Evolution of Army Style in the Modern West, 800-2000. *The International History Review* 18 (3):505-756

212 Diamond, Jared. 1997. *Guns, Germs, and Steel: The Fates of Human Societies*. New York: Norton, 53; Crosby, R. D. 1999. *The Musket Wars: A History of Inter-Iwi Conflict: 1806-45*. Auckland: Reed Books.

process that determined which sociotechnical configuration was dominant was independent of the social processes of the respective groups. In any battle, both groups have different interpretations about what the outcome of the battle should look like. The determinant of which interpretation survives involves a military process independent of the social groups concerned. The traits of the sociotechnical systems in battle are like the inputs to a function, where the structure of the function is independent of the input variables. Factors like morale, religious cohesion, enforceable discipline, training, and so forth, are all social variables, but they are inputs for the independently determined function of military superiority; they are variants to be selected by the military process of differential proliferation. The outcome of a battle is a probabilistic function of the weaponry used, the training and condition of the soldiers, the terrain, and other factors. Some factors lead to a higher probability of successful outcomes. Military competition, even without social processes such as imitation and learning, would lead to the evolution of those sociotechnical systems that are most effective at battle, in the circumstances in which they evolve. When we include imitation and learning as further mechanisms for sociotechnical interactors to evolve, we should expect even faster adaptation, as will be discussed in the section on Vicarious Selection.

To conceptualize from another vantage point, consider the game of chess. The players, and humans (and now computers) more generally, create strategies. The strategies are socially constructed (if we allow, for the sake of argument, that computers are social too). And yet, is there anything social about the dominant strategy? The rules of the game, and therefore the emergent topology of dominant strategies, are independent of the social processes of the players. The players imperfectly explore this topology so as to maximize their probability of success, but it is this emergent topology that "decided" which strategies would be maladaptive

against other strategies; at a young age I discovered that my favorite strategy of freeing my two rooks to roam the board was consistently beaten by most opponents, including myself. On occasion there will be a radical innovation in a game with static rules. In these cases, there must have been some social or cognitive constraints on all earlier variants, perhaps a critical missing technique. When the new innovation is finally discovered, the population of players will soon learn of its merit, and began employing it where appropriate. Social and cognitive processes are central to the construction of new variants; their success, though, is determined by the asocial selection environment.

Economic Selection. Within, or along with, every large sociotechnical interactor is some mechanism for deciding how to allocate resources and labor. These economic systems have a number of semi-social components. The economic processes of differential proliferation, especially under capitalism and anarchic political systems, tend to lead to outcomes that are, in most senses, autonomous of social control, for reasons similar to those applicable to military selection. While the demand for final goods are socially constructed, in the sense that they are a product of social actors, the economic system that evolves to serve these ends is often autonomous of the wishes of social groups, with the significant exception of when economic actors acquire substantial political influence.

To appreciate this level of selection, imagine a firm within a perfectly competitive industry. The demand for the product is set exogenously (by the consumers), as is the production function (by "nature").[213] The only choice that an individual firm has is what strategy it will adopt, and if it fails to adopt the most

[213] Mas-Colell, Andreu, Michael Whinston, and Jerry Green. 1995. *Microeconomic Theory*. New York: Oxford University Press

adaptive strategy, it will fail to survive, its resources being consumed by other more successful firms (sociotechnical systems).

Often, though, a firm can affect the demand for its product and its production function, through mechanisms such as advertising, regulatory capture, and lobbying. In some cases, as could be found most blatantly within a number of formerly communist countries, the economic proliferation (profitability) of a firm would be sustained by government decree and support.[214] In all these cases, economic processes blend with social, and thus these two processes of differential proliferation cannot be perfectly distinguished. Nonetheless, the fact that the production function—the various ways that people have for building things—is not entirely a product of social wishes, interpretations or decrees, leads to the possibility of deterministic outcomes from economic selection. To the extent that economic competition transcends political control, the technological trends associated with the increasing efficiency of production will likely continue. But, ignoring the unforeseeable future, the reader should remember that throughout history these economic trends have ultimately been enforced by military competition, which selected against any polity that had thoroughly mismanaged its economy.

Does economic selection necessarily have to be nested inside military selective processes? Yes and no: economic processes of differential proliferation always exist within a context of controlled potential violence (some property rights); but economic processes are not dependent on a particular interactor, they are capable of switching interactors and existing in many (that is, firms can move their capital, and exist within the control of multiple states). Many scholars argue that it was Europe's political anarchy that gave rise to early capitalism because merchants could always seek safe

[214] See the following for some astounding examples: Woodruff, D. 2000. *Money Unmade:Barter and the Fate of Russian Capitalism*. Ithaca, NY: Cornell University Press

haven in a less parasitical state; but it must be remembered that the reason that the interests of these merchants survived in and proliferated from these safe havens was because of the military advantages accruing to capitalistic states. Thus, while economic processes and actors can negotiate and gain power vis-à-vis states, they are ultimately dependent on some rule of force, and their power was always contingent on adaptiveness for higher order military competition.[215]

Social Selection. Trevor Pinch and Wiebe Bijker explicitly built their earliest formulation of the Social Construction of Technology on the selectionist logic advocated throughout this paper, inheriting their ideas from the evolutionary epistemologist Donald Campbell, an intellectual ancestor to most of the ideas in this paper. Bijker explains how these processes work under his model:

> A variety of problems are seen by the relevant social groups; some of these problems are selected for further attention; a variety of solutions are then generated; some of these solutions are selected and yield new artifacts. Such an evolutionary representation would thus not exclusively deal with artifacts, but would consist of three layers: variation and selection of (1) problems, (2) solutions, and (3) the resulting artifacts. Thus the results of variation and selection on the level of problems is fed into a further evolutionary process of variation and selection of solutions, which subsequently generate the artifacts.[216]

In SCOT's terms the selection pressures are not strictly economic or military, but are culturally constructed; the selection pressures are whatever criteria the relevant social groups use to judge the artifacts. In asking about these selection pressures, or "why some of the variants 'die,' whereas others 'survive'"[217] the analyst must "consider the problems and solutions presented by each artifact at particular

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[215] See McNeill for a summary of the strategic interaction between European merchants and kings: McNeill, William H. 1982. *The Pursuit of Power - Technology, Armed Force, and Society since A.D. 1000*. Chicago: University of Chicago Press.

216 Bijker. *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change* p 51

217 Pinch, and Bijker. The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other p 29

moments"[218] to particular groups. Thus, the selection pressures under SCOT are dependent on how the relevant social groups interpret the technology; weapons might be selected for their 'aesthetic beauty' or propensity for 'individual heroism' as much as for 'efficiency' or 'military superiority' – it all depends on the perception of the problem and solution by the relevant social groups.

Thus, SCOT should be conceptualized as a selectionist theory, in which the selection environment is entirely social. This theoretical underpinning was later neglected because the metaphor of evolution was thought to be too deterministic.[219] For the purposes of this paper, the explicit linkage between SCOT and selectionism situates SCOT well into the schema here developed. SCOT describes a context in which only social selection pressures are operative, and though SCOT does not discuss this in as much detail, it does not endorse any formal theory regarding the constraints on possible variants.

Thus, social selection is a well understood level of selection to sociologists and historians of technology. It is those contexts in which social groups select, through their consumption choices, interpretations, votes or actual use, which technical designs will proliferate. Social selection is likewise applicable to engineering design teams as they socially select which designs to work on, and what criteria they will privilege. In fact, most historical decisions about the future of sociotechnical configurations are socially decided (selected), explaining the prima-facie strength of the radical social constructivist position. Just as ecological selection is rare compared to military selection, all higher forms of selection are rare compared to social selection. Social selection operates on faster time scales than most cases of the higher levels of

218 Ibid. p 29
219 From a comment by Bijker during: Bijker, W. E. 2004. Roundtable Session: Twenty years after 'The Social Construction of Facts and Artefacts'. Paris, France: 4S/EASST.

selection, minutes or days for a social decision about the life or death of an idea or artifact, weeks or months for most economic "decisions" about a product or firm, years or decades for most military "decisions" about weapon system or state survival.

And yet, even for contexts in which only social selective processes are present, a unified evolutionary framework provides insight into the motives and beliefs of these social actors that a constructivist position may miss, because those motives have been shaped by higher levels of selection. This idea of vicarious selection will be discussed below.

Cognitive/Behavioral Selection. Finally, below social selection are the processes that give rise to individual behavior, which unfortunately is much less well understood than the higher levels. "Cognitive" selection refers to those processes when a human selects an idea to act upon, such as choosing a technical design to work on further. For example, some ideas may be difficult to conceptualize; these ideas, because of the adverse cognitive selection, will proliferate less rapidly than other more easily conceptualized ideas, all other things being equal. "Behavioral" selection refers to what humans can and tend to do, given the space of all possible behaviors. Some humans may want to fly unassisted, but this kind of behavior is constrained by behavioral selection.

These levels of selection have been introduced into Figure 9 as a background color gradient so as illustrate the relationship between different approaches to technology and the levels of selection that they tend to emphasize. Thus, scholarly approaches higher on the figure tend to emphasize those kinds of selection that are most deterministic (economic and military, and occasionally ecological), as well as

looking at longer time frames during when many selection events take place, even further reinforcing the processes that lead to technologically deterministic outcomes.

"Variation" Emerges from Lower Level Selection

The categories of variation and selection are analytical categories. The real world is not so neatly labeled. Given this conceptualization of the world, it should be noted that while the model of variation-selection may be suitable for any particular context, within a unified theoretical framework the categories blur. That is, the various traits of entities under one level of selection are themselves often the product of a process of selection at a lower level. Thus, the cognitive and behavioral products that emerge from cognitive/behavioral selection constitute the variants of social behavior. The products of social selection constitute the variants of economic selection; firms are made up of groups of human beings who advance the product designs which may lead to the economic success of the firm. The products of economic selection constitute the variants of military selection; states rely on their national economy to efficiently build their war-machine. The products of military selection constitute the variants of ecological selection; ironically, military and ecological selection seem to be so at odds that we often find that the most militarily adaptive interactors are ecologically maladaptive. The above figure, then, should also be read as indicating the units of variation (one level lower) for any particular level of selection.

Nested Hierarchies of Selection

Selection processes need not form a neat hierarchy as described, and there are certainly examples where multiple selection processes operate at the "same level," or selection processes at different scales are not neatly nested within each other. To a

certain extent, this formalization is a simplification to grasp the basic structure of different scales of sociotechnical evolution. However, in many cases selection pressures can be reasonably delineated in terms of different "levels," and they are often found in nested hierarchies. Historian of aerospace technologies, Walter Vincenti, employs the concept of Nested Hierarchies of Selection to explain how an airplane is built.[220] At a low level, individual engineers select amongst many design possibilities. At a higher level, groups of engineers discuss amongst themselves which design possibilities are the most promising. At a still higher level, these engineers test their few preferred designs in simulated environments, such as a wind tunnel. Those designs which, when built, are most successful at the various tests, are then built into planes for the final test. Over time, these plane designs are compared to each other, and firms will imitate the technologies of their more successful rivals.

Vicarious Selection

The nested levels of selection are not independent each other. Rather, the higher levels structure the lower levels (through the process labeled ultimate, functionalistic, or downward causation) so as to be most adaptive for the higher levels. That is, higher level interactors evolve internal selection environments that are themselves adaptive for the higher level interactor. To see this, Vincenti's example is helpful.

An aerospace firm would not succeed if its internal components acted irrespective of the needs of the larger interactor (the firm's profitability). Rather, the larger interactor actually shapes the nested lower levels of selection in such a way as to maximize the larger interactor's fitness. In order to do this, the larger interactor

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[220] Vincenti, Walter G. 1990a. *What Engineers Know and How They Know It - Analytical Studies from Aeronautical History*. Edited by M. R. Smith and T. P. Hughes, *Johns Hopkins Studies in the History of Technology*. Baltimore: Johns Hopkins University Press.

forms internal representations of the external selection environment, so that its internal selection processes can quickly adapt to the needs of the larger selection environment. Thus, rather than going through the costly process of building and testing a new plane for every wing design, the firm internalizes the selection pressures (aerodynamics, cost of materials, etc.) and designs new traits (planes or parts of planes) in *vicarious selection* environments. Engineers test new wing designs in a wind tunnel first; other employees calculate the expected cost of the different materials used in these proto-designs and *select* the design that best balances the internalized representation of the cost/effectiveness trade-off. At a lower level, design teams select those designs that they think have the best chance of success according to the firm's needs, not based upon whatever notion they happen to have, but based upon ideas and attitudes that themselves have been selected for their past success (either in university, or in employment—few employers hire a design team leader who consistently builds overpriced, dysfunctional prototypes). Even the cognitive selection taking place within every engineer's mind reflects the larger physical and economic reality, internalized through years of education and work experience. A successful interactor is one which has sub-components (and sub-sub components) that each adapt themselves to the specific needs of the larger interactor. Thus, even when we look just at the level of social selection, an evolutionary approach hypothesizes that we will tend to find attitudes and cognitive representations that are largely adaptive for the larger interactor (if this interactor exists in a competitive milieu). Personnel within economic firms and military organizations behave in particular ways, not just because that is the idiosyncratic life history of this socio-cultural entity, but partly because there has been selection for adaptive ways of behaving which internalize external selection pressures.

With this concept of vicarious selection we have a useful mechanism for explaining why we may have such deterministic tendencies in history though with so few deterministic selection events (most evolution takes place through imitation, not the death of stubborn interactors). Cognitive routines, people, design teams, firms, and states (and any other interactor) do not generally stubbornly cling to unsuccessful configurations. Rather, at some point the maladaptiveness of the configuration becomes clear through some signal (such as a drop in the stock price, or a major military failure) and the interactor begins to self-consciously adapt to its perceived selection pressures. At this point, all the problems made clear by the study of the Social Construction of Knowledge are present: representations are always imperfect because they are necessarily indirect social constructions. However, an evolutionary framework makes clear that the sociotechnical mechanisms that interactors use to form representations of the external selection environment has *itself* been selected in the past for its effectiveness. Thus, much like how the human eye was selected for its ability to perceive color and motion over those wavelengths most relevant to our ancestors, our sociotechnical routines for vicarious selection have been selected for their ability to internalize the external selection environment. The behavior of engineers within a firm trying to understand the external selection environment facing an airplane does not arise willy-nilly, but emerges from years of evolution in which other firms, pedagogical strategies, and testing techniques have themselves been selected.

This evolutionary insight also explains why large organizations so often require strong adverse signals before adaptation begins—why, as the saying goes, the military is always preparing to fight the previous war. Organizations and individuals are adaptively rational, learning from trial and error in past selection environments; they are not perfectly rational or otherwise. While higher level selection events are

rare in history, lower level interactors will internalize the higher selection environments, thereby internalizing the tendency to evolve towards greater adaptiveness (for the higher selection environment). With vicarious selection, then, the processes of differential proliferation due to military and economic competition that give rise to technologically deterministic trends will be manifest in lower level social and cognitive processes. Thus, while many scholars are right to point out that it is the spread of certain cultural beliefs that sustain technologically deterministic outcomes, they are wrong to suppose that these *beliefs* may not be supported by and based upon powerful external processes.

I have constructed a table to elaborate the concept of a nested hierarchy of selection, based and extended upon Vincenti's example in aerospace design:

Level of Selection/ Scale of Analysis	**Competition Among[221]:**	**Examples**	**Selective Agent**	**Selection for:**
Macro-Economic-Military	-economic regions, states, cultures	1)Booming economy from cost-effective aeronautical transportation. 2) Aerial combat and campaigns (strategic bombing).	Emergent 'rules of the game'. (eg. Who selects what strategies are adaptive (will win) in chess?)	Adaptive sociotechnical systems based on emergent criteria; may exhibit deterministic trends.
Meso-Politico-Economic	-systems, corporations or industries	Profitability of airline industry.	Consumer. Political (& cultural) climate.	Technical-economic-macro-social characteristics based on social, economic and political determination of criteria.
Micro-Economic	-products or components of systems	Sales to a hobbyist or commercial consumer.	Consumer (price, ideology, effectiveness)	Technical-economic characteristics based on social and economical determination of criteria.
Technical Feasibility	-artifacts	A test flight of a new plane design.	Physics as it relates to full artifact and selection criteria.	Technical characteristics based on socially internalized criteria.
Testing (Vicarious Selection)	-artifacts, or components of artifacts	A wing in wind tunnel.	The laws of physics as it relates to the testing setup and criteria.	Technical characteristics based on socially internalized criteria.
Group Discussion (Vicarious Selection)	-ideas -plans -strategies -blueprints	Engineers strategizing how to build a wing.	Shared cognitive perspectives. Social relations.	Socially internalized characteristics.
Individual Cognitive (Vicarious Selection)	-ideas	An engineer's self-rejection of his own idea.	A schooled mind. Intuition. Internalized experience.	Cognitively internalized characteristics.

Figure 10 - Levels of Selection/Scale of Analysis (begin reading at the bottom)

221Also often called the Interactor, which is defined as, in David Hull's words, "that entity for whom its characteristics will most directly determine the proliferation rate (of the interactor and replicators)."

Agency and Determinism in Evolution

We return to the issue that motivated this paper: the question of historical agency. Agency is defined as the ability to perturb the historical trajectory in an intended manner (thus, unintended perturbations do not count).[222] From an evolutionary point of view, there are two processes that define the extent to which an individual or group can perturb a system in an intended way: the processes of 1) upwardly causal variation and 2) downwardly causal selection. The first process, as previously mentioned, is the typical run-of-the-mill kind of causation: an actor or group can do whatever it can do (which itself is a difficult analytical problem to resolve). The second process asks what will happen in the long run in a selective environment to the possible variants of different interactors: will an action help or hinder the acting entities struggle for existence against economic, military, and ecological selection.

222 Following from Elster's formalization: Elster. *Explaining Technical Change*, 32.

Weak Selection, Extensive Variation. Under contexts of weak or no selection, the question of agency is the conventional problem dealt with by non-evolutionary social scientists. The problem is a complex one. Radical social constructivists represent the most extreme position in this typology, since they argue that individual human actors have limitless (or no definable limits on the) possibility to reinterpret and reconstruct their world. In this case, each actor has unlimited, or an undefinable, degree of agency; if an actor can reinterpret their world however they please, then are they not perturbing their own historical trajectory to suite their interests? Even less realistically, if an actor is capable of almost any action, than the only constraints facing this actor's agency is the unpredictability of consequences stemming from the complexity of the system. If the system is too complex, then the ability to act is futile because it cannot bring about predictable change. Most scholars of social systems introduce some constraints on possible action.

Weak Selection, Constrained Variation. One set of scholars argues that human and social variation is constrained or determined by our cognitive or behavioral disposition, that is humans actually have far less choice in our behavior than we like to tell ourselves. Our beliefs and motives are structured or determined by: genes, childhood, socialization or other environmental factors. To these scholars, an individual has "agency" to the extent that she can choose to act despite her innate inclinations. At this level, the question of agency is almost philosophical because it involves distinguishing the "will," whose agency we are concerned about, from other aspects of the "programmed" self.

More scientifically, we can ask how much controlled difference any historical actor or group could have made to the historical trajectory, as if their behavior was

solely a product of will. Most of these scholars acknowledge that resource availability (both natural and political) heavily structures our space of possible decisions. These scholars can be said to ascribe to technological momentum, since resource availability is partly a product of past political decisions. To these scholars, then, the agency of all humans (the possible perturbation if all humans acted in concert) is undefined, but the agency of individual humans is constrained by past actors. One possible framework holds that some actors have tremendous agency (to build low-hanging bridges, for example) while others have little. The political calculus that determines who has power and who doesn't remains undefined for most theories, but without some exogenous sources of power, these theories should be strictly passive in the sense that they at most propagate the interests of past actors. With some exogenous source of power, these theories introduce economic or military processes of selection. An alternative framework that some scholars may hold is that agency is constrained by past actions, but that the system is sufficiently complex for actors to effect predictable consequences, and thus all actors are equally constrained by the random vagaries of past actions.

Strong Selection, Extensive Variation. Under this ideal-typical adaptationist context, the space of possible variation from the lower level (be it cognitive/behavioral, social or otherwise) is relatively extensive. Social groups are highly plastic, capable of an amazing and under-observed breadth of organization. At the same time, selection pressures are ideal-typically intense, with a large population of interactors immersed in intense military and/or economic competition. Under this historical context, human actors have a very small space of choice: they may choose to pursue the adaptive solution, or they may choose to perish or be controlled. In either case, the "free" actors are those who are choosing exactly what they must—these actors are only free in the trivial sense of being able to choose whether they will lead adaptation, or be forced into it by another interactor, or eliminated.

To illustrate the context, ponder the freedom of action that the a world chess champion, such as Gary Kasparov, has in his games. If Kasparov only plays against his nephew, he could play just about any move that he wants. If Kasparov is playing a ranked tournament, though, he is compelled to play the moves most likely to give him a win, because he is motivated to hold his title. But even if Kasparov's motives changed, and he no longer cared about the prize money, fame or title, what would happen? Kasparov could make whatever move he pleased, but if he chose to make maladaptive moves he would quickly lose his title, and his admission to world championships. At this point, Gray Kasparov the human being could still play chess however he pleased, but Gary Kasparov would no longer be the world chess champion. Instead, someone else would become the "world chess champion," and would select movenos from the vanishingly small set of best moves. In the world of grandmaster chess, Gary Kasparov and his "irrational" moves had been selected against, replaced by an interactor willing to make the moves that he wouldn't (though probably to a marginally less adaptive extent). Under strong selection pressures, as

was often formerly the case in our world of inter-state conflict, and is largely the case in our world of inter-firm competition, leaders of interactors are constrained to act in the best evolutionary interests of their interactor. Unless our global society is able to fully reign in the forces of military and economic competition, then the world's interactors will continue to adapt to selection pressures not of our choosing (mostly economic), and possibly not to our long-term benefit under ecological selection pressures. To the extent, then, that individuals or groups can control the long term selection pressures of military and economic competition, they may have agency over their long-term future. Enduring political power does not come from one-step reinterpretations of a situation, or simple pluralistic decision processes, but from the reshaping of the selectionist topology in which the large interactors are adapting.[223]

223 To control military competition, the founders of the League of Nations struck on the best solution that I know of to date: a shared military force that is obliged to intervene in certain cases of aggression. To control economic competition, "true-cost pricing" should be sought through appropriate taxes and subsidies. This will increase market efficiency, and if used appropriately, can also introduce social values into market mechanisms (say, for example, by subsidizing companies that provide fulfilling, skill-developing employment). These prescriptions deserve further elaboration elsewhere.

Strong Selection, Constrained Variation. Perhaps ironically, having certain kinds of constrained variation that lead to path-dependent outcomes can increase the agency of certain actors even in a highly selectionist environment. In the presence of economies of scale, the "first mover" advantage can often outweigh other factors in determining which interactor will proliferate. The classic example given is that of the QWERTY keyboard, that is allegedly much less efficient than other keyboard designs such as the DVORAK keyboard, but became the dominant design because it achieved early dominance through its use in typewriters.[224] Thus, even though technologies of information production exist in a highly competitive environment, some of these technologies have such strong path dependence that other traits of the interactor make little difference next to contingent, idiosyncratic events that perpetuate this form through time.

To the extent that there are these path dependent processes (stemming from positive feedback processes), detailed historical narrative regains its importance as the best generalizations that social science can hope to offer: social systems in these contexts are contingent. The question remains empirical: to what extent do military and economic processes of differential proliferation select for adaptive sociotechnical configurations, as opposed to history being driven by contingent trajectories, social selection or other processes. Or, in the economic language of Paul David, would "the agents choosing one or another path [have been] led back to a single, globally stable attractor of the kind that characterizes a[n] ergodic dynamical system."[225]

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224 David, Paul. 1985. Clio and the Economics of QWERTY. *American Economic Review* 75 (2):332-337

225David, Paul. 2005. At Last, A Remedy for Chronic QWERTY-Skepticism! Stanford, CA: Stanford University

Does Technology Drive History?

Under the specific range of evolutionary parameters, then, we can make sense of the claim that technology may in fact drive history. Technology enables new sociotechnical variants—if there is an agreed definition for technology it is this. Processes of differential proliferation select a subset of variants to proliferate. Therefore, under intense, constant selection pressures, a new technology, by expanding the range of possible sociotechnical variation, enables new adaptive forms, which will proliferate, radically transforming the population of interactors (see Figure 11). Lynn White was right to note that technology "merely opens a door; it does not compel [us] to enter."[226] It is military and economic competition that shoves us through.

226 White. *Medieval Technology and Social Change*, 28.

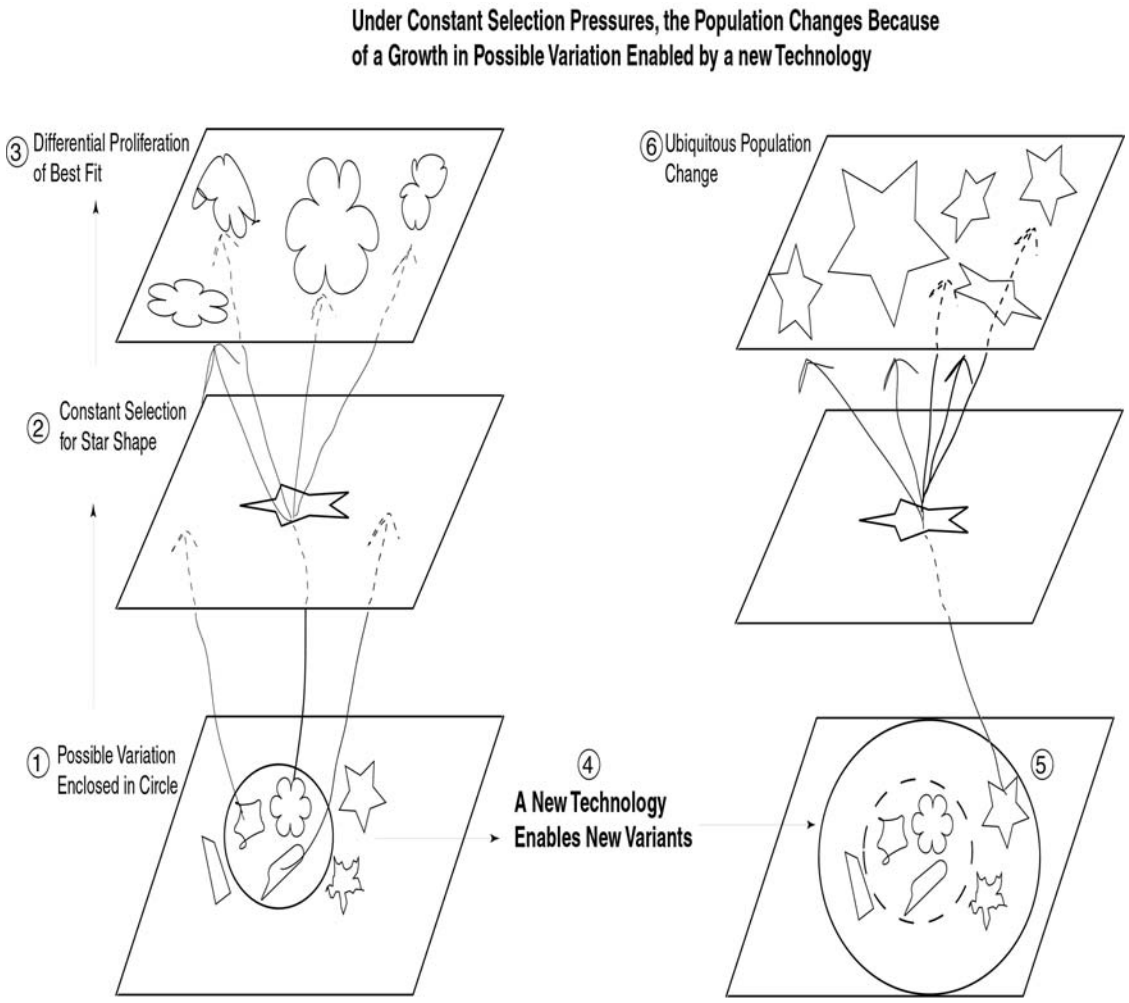

Figure 11 - Technology Opens the Door, Competition Shoves us Through

Figure 11 illustrates how a new technology, in a competitive environment, can cause radical social change. (1) On this plane are represented six theoretically possible sociotechnical configurations. Only the three configurations encapsulated by the circle can be realized with the current level of technology. (2) The selection environment selects for "star shaped" configurations. (3) Only the "flower" shape proliferates, because the other two shapes are not sufficiently star shaped. This world, then, consists of variations of the flower shape.

(4) A new technology arrives, through imitation or invention, and enables three new variants, (5) as illustrated by the expanding circle of realizable

sociotechnical configurations. Under the same selection pressures, a new variant proliferates, leading to (6) radical and ubiquitous population change. A macro-historian of this world would see a population of flower shapes (3), a new technology arrive (4), and then a population of stars (6). They would be correct to say that the technology (4) changed the world (3) –> (6). An evolutionist could explain how.

We could narrate this figure with an actual historical example: for example, Pelto's account of the change in reindeer herding practices by the Skolt Lapp's after the introduction of the snowmobile.[227] The Skolt Lapps, for over a hundred years, had herded reindeer throughout the winter using dogsleds and skis (= flower shape). (1) This method worked.(2) The consequent social structure was highly egalitarian, all were "employed", and pre-modern. (3)

With the introduction of Snowmobiles (4), a number of new herding strategies became possible. (5) One of the new strategies was to let the herd run "wild", and to later bring them in with an organized snowmobile corral (= star shape). Those who adopted this strategy were successful and made money, while many of those who didn't (= flower shape), or failed to do so effectively (= wriggly star), had to sell their herds and seek wage labor. The population of reindeer herders, then, was radically transformed (6) in just a few years, caused by the introduction of a new technology into a competitive system.

[227] Pelto. *The Snowmobile Revolution: Technology and Social Change in the Arctic*.

Case Study

What would counter-evidence to a sociotechnical evolutionary theory of technology and history look like? An historical case that would provide substantial counter-evidence against a sociotechnical evolutionary theory, and in favor of a social constructivist argument, would involve an interactor amidst a competitive milieu whose behavior could not be explained by adaptive considerations (and should thus diverge from the behavior of similar other interactors) but could be explained exclusively or primarily by consideration of social factors internal to the interactor. More concretely, an empirical socially constructivist rebuttal to the military Darwinist's argument would require showing a historical case where a military interactor chose to pursue inferior military techniques for social constructivist reasons, and was able to survive. A number of possible case studies could be examined to plausibly provide such a challenge to evolutionary theory, such as when interactors collectively fail to embrace a superior technology, as with the reluctance of European powers to adopt the (in retrospect powerful) machine gun in World War I, a collective rejection of ostensibly superior technologies, as with the Chemical Weapons Convention, or a sustained deviation from an adaptive evolutionary trajectory as with the Japanese "reversion to the sword."

In this paper I have chosen to focus on the latter example because it represents one of the strongest possible refutations to a directional evolutionary understanding of technological change under military selection. This "historical regression" is one of the most significant counter-examples to a strong sociotechnical evolutionist thesis because it purports to show how even the development of a critical military technology was not determined by a logic of military-technological supremacy, but

was radically shaped by local social forces, thus revealing the breadth of possible historical choice and contingency.

In this case, however, the exception proves the rule. Japan "regressed" in military technologies only for that period characterized by a lack of military competition, caused by centralized rule and the absence of foreign military threats. During the periods prior to and after Japan's "regression," when military conflict was present, military technologies rapidly developed, as an adaptationist would expect. Furthermore, it turns out that the Noel Perrin's compelling message of social agency over technology, to quote the sympathetic postscript of the Japanese translation of his book, does "not take as its goal the empirical examination of the events of the past."[228] In other words, Perrin overstated some of his factual claims so as to make a broader theoretical argument, a surprisingly frequent academic occurrence.[229] Nonetheless, Japanese firearms technology did radically regress during the Tokugawa period, temporally sandwiched between two periods of rapid development in firearms technology. This radical regression poses a challenge to the sociotechnical adaptationists analysis. In the following pages, these three periods will be discussed, providing an opportunity to illustrate some of the theoretical themes of sociotechnical evolution.

The story of firearms in Japan has can be divided into three periods. The first, from the introduction of guns in 1543 to the unification of Japan under the Tokugawa Shogunate in 1603, follows the adaptationist 'diffusion of innovations' narrative: guns were introduced, were immediately recognized as powerful, and proliferated throughout the country. The second period follows a plot line less familiar to

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[228] Quoted in Chase, Kenneth. 2003. *Firearms: A Global History to 1700*. New York: Cambridge University Press, 253.

[229] For a deconstruction of Winner's Bridge example, see Joerges. Do Politics Have Artefacts? . For a similar critique of Pinch and Bijker's historical case, see Clayton, N. 2002. SCOT: Does it Answer. *Technology and Culture* 43 (2).

Westerners. The island of Japan, controlled by the Tokugawa Shogunate, gradually, over a hundred years, eradicated firearms from the commoners and drastically reduced gun-smithing from the economy. The strength of the samurai class, the repugnance at foreign influence, and the cultural valorization of the sword as a heroic and spiritual weapon have all been offered, most notably by Noel Perrin, as partial explanations for this dramatic 'regression'. As such, this period seems to lend itself readily to a social constructivist analysis. Though a constructivist approach provides insight to the processes at work during this period, it remains insufficient because it ignores the historical context that allowed this technological regression, namely: the absence of military competition. Finally, the third period begins with the submission of China during the Opium Wars and Commodore Perry's 1853 demand that Japan open itself to trade. Following Perry's visit, debates raged and civil war flared up over the question of how Japan should meet the threat of the foreigner. A complex back-and-forth process took place in which various groups eagerly adopted the West's technologies so as to better reject the West's political and cultural encroachment. The industrialization and modernization of Japan followed the outcome of this national decision.

The Evolution of Firearms Through Japan: 1543-early 1600s[230]

Tanegashima

In 1543, a Chinese vessel brought some Portuguese adventurers and their arquebuses to the shores of Tanegashima, a small island off the southern coast of Japan. These guns came to the attention of the feudal master of Tanegashima, Lord

[230] I owe a great debt to Noel Perrin's *Giving Up the Gun* which was the text that first pointed me to Japan's interesting military history. Through few, if any, Japanese historians of this period accept Perrin's strong cultural claims, his text provided an effective entry point into the question of why Japanese society "regressed" as it did.

Tokitaka, who asked for firing lessons and later paid an extraordinary sum for the two guns. Tokitaka ordered his chief swordsmith to reverse engineer the guns. Within a year the first ten native Japanese guns had been made, "by the end of the decade it was possible for firearms to decide the outcome of battles."[231]

Firearms were so immediately embraced that by 1549, Lord Oda Nobunaga, who later, with the help of his successor Toyotomi Hideyoshi, unified Japan, placed an order for five hundred 'tanegashima' (the early Japanese word for matchlocks, reflecting their geographical origin).[232] By 1571, only twenty-eight years after the first arquebus came to Japan's shores, Takeda Shingen, who controlled one of the largest Japanese armies, ordered his commanders that "Hereafter, guns will be the most important arms. Therefore, decrease the number of spears [in your armies], and have the most capable men carry guns."[233]

Nagashino

The importance and effective use of guns found fullest expression in the 1575 battle of Nagashino where one quarter of Oda Nobunaga's army of 40 000 was armed with matchlocks, and "of these, the three thousand best trained were the chief cause of his great victory."[234] Lord Oda arranged those three thousand matchlockmen to stand behind a stream and a palisade, with orders to fire in groups of a thousand men, and for all to hold their fire until the enemy was close, a "key tactical innovation" that was "independently discovered, at about the same time as Western Europeans."[235] Oda's

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[231] Chase. *Firearms: A Global History to 1700*, 179.
[232] Brown, Delmer. 1948. The Impact of Firearms on Japanese Warfare, 1543-98. *The Far Eastern Quarterly* 7 (3), 238.
[233] Turnbull, S. R. 1977. *The Samurai: A Military History*. New York: Macmillan Company, 140.
[234] Perrin, Noel. 1979. *Giving Up the Gun - Japan's Reversion to the Sword, 1543-1879*. Boston: David R. Godine, 19.
[235] Hoffman. Why Is It That Europeans Ended Up Conquering the Rest of the Globe? Prices, the Military Revolution, and Western Europe's Comparative Advantage in Violence. At: http://gpih.ucdavis.edu/files/Hoffman.pdf, 3. Access Date: 24/06/2006

enemy, Takeda Katsuyori, ordered his cavalry to charge the central palisade. When the cavalry reached the edge of the stream:

> . . . a devastating volley from a thousand arquebuses tore into them. Volley after volley followed, until men and horses were scattered around the slopes. . . . Katsuyori then ordered up his reserves, and personally led an assault on the stockade. But the alternate volleying was still calm, controlled and efficient. Every twenty seconds a hail of bullets tore into the ranks and blasted the Takeda samurai to eternity.[236]

The Battle of Nagashino was paradigmatic of the revolutionary changes taking place in military tactics and weaponry in Japan in which "muskets and pikes came to dominate the battlefield and cannon beg[an] to influence siege and naval warfare."[237] Future military conflicts looked like they would rely more on a disciplined and distanced use of firearms than on the traditional "monster fencing matches,"[238] courageous cavalry charges, and legendary heroic duels. This period exemplifies the adaptationist paradigm in a number of ways: 1) the adaptive technology diffused broadly and rapidly, as expected by the 'diffusion of innovations' school; 2) the adaptive technology and the means of its manufacture were improved upon; 3) the larger interactors were reconfigured to better exploit this new technology through altered tactics, factor prices, and logistics considerations.

Cannon technology likewise proliferated during this time because of its military advantages. Nobunaga, in particular, "built seven large ships armed with cannon and plated with iron" which he sent to blockade a recalcitrant Ōsaka. During 1578 his ships came under attack by hundreds of smaller boats; "the cannon on Nobunaga's ships kept the smaller enemy ships at bay and prevented them from

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[236] Turnbull. *The Samurai: A Military History*, 148.
[237] Chase. *Firearms: A Global History to 1700*, 182.
[238] Brinkley, Frank. 1901. *Japan, its history, arts and literature*. Vol. 2. Boston: 1901, 133, quoted in Brown. The Impact of Firearms on Japanese Warfare, 1543-98.

approaching. . . the cannon on Nobunaga's ships prevailed."[239] Cut off from the ocean, Ōsaka was forced to surrender.

By 1590, less than 50 years after firearms first arrived, Nobunaga's successor, Toyotomi Hideyoshi, had unified Japan. The age-old conflict between different warlords on Japan, during these years, had undergone a phase-shift due to the introduction of firearms. Kenneth Chase, in his excellent global history and analysis of firearms, explains how firearms:

> . . . confer[ed] an advantage on the larger warlords. . . creat[ing] a snowball effect that helped make unification possible.
>
> When armies were composed of mounted warriors, large armies were difficult to hold together. The individual warriors had political ambitions that outweighed their loyalty to their superiors. . . .
>
> When armies came to be composed of footsoldiers armed with pikes and firearms, the advantage went to the warlords who commanded larger populations and greater resources. Because anyone could be trained to wield a pike or fire a musket, large armies could be assembled by recruiting and training peasants. Insubordination became more difficult, as the organizational demands of supporting an army increased. Defeat was more decisive, as an army could not continue to resist for long after its source of supplies and ammunition was overrun. It was now possible for a single leader to grow at the expense of his rivals without becoming vulnerable to his own subordinates.[240]

Delmer Brown concurs, adding that firearms gave new superiority to those military entities that could best coordinate their gunners and footsoldiers:

> . . . the military advantage came to lie with large armies under a central command—a significant factor in the concentration of military power that led to the establishment of a single government for all Japan in 1590, fifty years after guns were first used in Japanese warfare.[241]

This period lends itself perfectly to a sociotechnical adaptationist analysis. The critical factor shaping history during this time was not the actions and

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[239] Chase. *Firearms: A Global History to 1700*, 183.
[240] Ibid., 184.
[241] Brown. The Impact of Firearms on Japanese Warfare, 1543-98.

interpretations of individual warlords. In fact, the unifiers didn't even have a "decisive superiority in firearms,"[242] nor were they preternaturally insightful as to the advantage of firearms, as "the effectiveness of firearms was recognized by most if not all the major warlords."[243] Instead, the trajectory of history towards a unified Japan was impelled by the altered strategic environment in which larger peasant-based musket-wielding armies tended to dominate. Firearms changed the relative advantageousness of different military configurations providing large returns to the scale of the army, in the sense that those warlords who could field and support the largest pike-musket armies had a decisive advantage. To the extent that the claim that firearms gave an advantage to the larger military power is valid, an adaptationist would be correct to argue that the unification of Japan during this period was largely inevitable. Lords Nobunaga and Hideyoshi were central figures in this history, and an understanding of the specific details of Japanese history requires careful attention to their choices. But the general pattern of Japanese history, if there are large military returns to scale of firearms, is indifferent to these individuals' particular genius and ambition, for if they had chosen a less-expansionistic path, another contending warlord would have come to dominate.

In theoretical terms, there existed a large population of competing interactors (warlords). Each interactor was capable of a breadth of variation, thanks to the absence of a monopoly on any military technologies, helped in part by the presence of foreign powers who were willing to trade. All variation but the most adaptive, however, was futile, doomed to be eliminated by the other proliferating configurations. There was little room over the long run for substantially varied interpretations of firearms and military tactics. Military competition was intense and

[242] Chase. *Firearms: A Global History to 1700*, 183
[243] Ibid., 184.

ubiquitous, such that the larger power tended to emerge victorious and thereby accrue still more population and territory. The inevitable outcome to this idealized system is a population of a single large interactor, at which point either the competitive system must expand overseas or the competitive process must come to an end. Interestingly, first the former, and then the latter, took place.

The Japanese Invasions of Korea

Hideyoshi, after seizing control of Japan, led an invasion of the continent, beginning in Korea. The initial attack was dramatically successful, "due in large part to [Japan's] superior muskets."[244] Throughout the invasion the usefulness of firearms was appreciated to an even greater extent, such that a Kyushu lord writing home requested:

> Please arrange to send us guns and ammunition. There is absolutely no use for spears. It is vital that you arrange somehow to obtain a number of guns. Furthermore, you should certainly see to it that those persons departing [for Korea] understand this situation. The arrangements for guns should receive your closest attention.[245]

The first invasion of Korea eventually ran out of steam due to the resistance of the local population, the success of the Korean navy at disrupting Japanese supply lines, and the arrival of Chinese reinforcements. During this respite, the Koreans adapted their tactics, fortifications, and armaments to better equip them for battle against the musket-based Japanese armies.

During the second Japanese invasion of Korea the "proportion of musketeers rose"[246] in the Japanese forces, a fact that helped them considerably against the

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[244] Ibid., 186.
[245] Quoted in Brown. The Impact of Firearms on Japanese Warfare, 1543-98. , 240.
[246] Chase. *Firearms: A Global History to 1700*, 190.

Chinese reinforcements, which outnumbered the Japanese by 2 to 4 times.[247] At one point a Japanese commander wrote home further requesting that:

> When troops come [to Korea] from the province of Kai, have them bring as many guns as possible, for no other equipment is needed. Give strict orders that all men, even the *samurai*, carry guns.[248]

During the invasions of Korea, because of the extensive integration of firearms technology and tactics into their armies, the Japanese had demonstrated superiority at battles in the open with the Koreans and Chinese.[249] The second invasion of Korea, nonetheless, did not have enduring success for the Japanese, owing to the numerical advantage, naval advantages, other tactical and technological advantages, and the adaptability of the defenders. This period provides "yet another reminder, like the Chinese experience in Vietnam, that advanced weaponry does not guarantee victory,"[250] or in other words, that military competition does not select for simple, unidimensional configurations. Military selection, like most selectionist processes, are complex, context dependent, relative to the configurations of other interactors, and non-linear.

This does not mean, however, that we are unable to say anything about that which is adaptive. Rather, it means that we have to appreciate that the adaptive topology is complex, and that many variables need to be specified. In our case, the evidence suggests that the effective use of firearms provided a significant advantage to military conflicts in the open. Since military conflict in Japan was largely characterized by conflict in open areas, the most adaptive military interactors were, as in Europe, those that employed firearms in substantial numbers and in a well ordered manner, protected at close range by pikemen and swordsmen. Since the distinctive

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[247] Brown. The Impact of Firearms on Japanese Warfare, 1543-98. , 241.
[248] Ibid., 241.
[249] Chase. *Firearms: A Global History to 1700*, 192. Italics in original.
[250]

inputs for this kind of military configuration are access to firearms, ammunition, and a large population, and inferring from the evidence that there were increasing returns to the expected success of a military confrontation from the scale of the army, a sociotechnical adaptationist would concur with the "generally accepted [view] that firearms contributed greatly to the unification of Japan."[251]

Firearms thus proliferated because:

> Everyone recognized their superiority as long-range killing devices, and all the feudal lords ordered them in large numbers. At least in absolute numbers, guns were probably more common in Japan in the late sixteenth century than in any other country in the world.[252]

The fifty years following the introduction of guns to Japan, therefore, provides an ideal illustration of a sociotechnical adaptationist's expectation of the proliferation of an adaptive technology: being advantageous, firearms diffused broadly and rapidly and continued to be improved within the competitive warlord system. A few military actors acquired and learned how to use firearms in some contexts; the success of those actors who embraced firearms led to the proliferation of the use of firearms, through both the proliferation of the actors who used them (by acquiring more territory and people) and through imitation by others.

After the second failed excursion into Korea and the death of the leader Hideyoshi, the Japanese state, soon to be called the Tokugawa *bakufu*, went into a 250 period withdrawal during which there were no battles in Japan[253] and little contact with the outside world. A sociotechnical adaptationist would be at a loss to explain what had transpired. Matchlocks became increasingly rare, and the industry to manufacture them dwindled. The dramatic "reversion to the sword," to quote Perrin's subtitle, stymies a simplistic adaptationist explanation, and instead offers a plausibly

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[251] Chase. *Firearms: A Global History to 1700*, 183.
[252] Perrin. *Giving Up the Gun - Japan's Reversion to the Sword, 1543-1879*, 25.
[253] Except for two rebellions, one in 1637-38 and one in 1837.

compelling case against a technologically deterministic analysis and in favor of a more socially constructivist perspective.

Japan's Reversion to the Sword: late 1500s-1853

Firearms did not vanish from Japan overnight. Through a series of governmental policies, which covered the now-unified Japan, possession of guns (along with other weapons) was first limited and then forbidden to commoners. Manufacture of guns was centralized, controlled and scaled down. By 1668 the government had placed its last order of guns from Sakai, the only remaining region of Japan where guns were produced.[254] Gradually Japanese samurai gave up their practice of fighting with firearms:

> The samurai went back to taking fencing lessons, the monks resumed making black-feathered arrows, and all over Japan skilled smiths poured out a never-ending stream of top quality armor and swords.[255]

An adaptationist would explain technological change by appealing to the superiority of the more recent technology. Japan's matchlocks were not replaced by the flintlock firearms as occurred elsewhere in the world, though, but by their antecedent (though likely improved) weapons: swords, arrows, and spears. A constructivist analysis, on the other hand, could offer a plausible explanation for why Japanese weapons developed as they did, beginning with a simplified enumeration of the relevant social groups, in this case: 1) the samurai, 2) the peasants, and 3) the Shogunate (government of the Shogun).

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[254] Perrin. *Giving Up the Gun - Japan's Reversion to the Sword, 1543-1879*, 64.
[255] Ibid., 69.

The Samurai

The samurai, like feudal lords throughout Europe, were probably impressed by the military power of firearms but resentful of their social consequences. The samurai made their living and justified their elite caste status by serving as professional swordsmen for their feudal lords. Firearms undercut this claim by changing the tactical topology of military conflict, and undermining the military utility of the samurai. A peasant could, "be taught within a few days to shoot an arquebus with all the accuracy of which the weapon was capable."[256] Thus, not only was any peasant capable of firing a weapon that could penetrate the armor of the highest samurai, but increasingly a disciplined use of muskets proved to be a superior battlefield tactic to archery, the cavalry charge, and the legendary sword duels. By undermining the military usefulness of traditional samurai skills, firearms threatened: 1) the samurai's elite social position; 2) the heroism, glory and norms of traditional combat; and 3) the potent meaning of the sword as a symbol.

Addressing the second point, battles changed dramatically under the influence of firearms. Whereas previously the combatants would ceremoniously introduce themselves and "exchange ritual compliments before the slaughter began,"[257] the great tactical advantages of firing from a distance eventually came to dominate the battlefield rituals. Furthermore, courageous legends and tales of heroism did not emerge naturally from the effective use of firearms. Bravery and individualism were no longer militarily beneficial, but rather patience, discipline, and effective logistical supply.

The sword was also a potent cultural artifact. A famous Japanese quote calls it 'the soul of the Samurai,' and as such it embodied the heroism and honor of the

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[256] Turnbull. *The Samurai: A Military History*, 131.
[257] Perrin. *Giving Up the Gun - Japan's Reversion to the Sword, 1543-1879*, 22.

bearer. Instead of wearing epaulets or military decorations, the Japanese warrior's heroism was represented in the craft and beauty of his sword. Bearing a sword indicated the right to have a family name. Samurai were distinguished by their exclusive right to carry two swords. The most ironic expression of the value of swords occurs in 1605 when the shogunate wished to reward four outstanding gunsmiths; he gave each of them a sword![258]

The Samurai class, as a *relevant social group*, clearly had a distinct interpretation of the meaning of the sword. Firearms represented a threat to their lives (since a samurai in full armor could be felled by an anonymous peasant hiding in the bushes), to their economic and social status, and to their precious, even spiritual, cultural artifact: the sword. Representing an elite 7-10% of the population,[259] the samurai were not only a social group with a coherently negative interpretation of firearms, but a group with a lot of social influence.

Additionally, it should be pointed out that 'the samurai,' as a class, was itself changed by the social negotiation of firearms. In fact, 'the samurai' became a much more coherent and closed class following the banning of firearms and related general restriction on peasant possession of weapons.

The Peasants

The second social group is difficult to define: vast in that it comprised the majority of the population, but also underrepresented in the historical record. The peasants are usually assigned passive roles in history's retelling, except for the occasional revolution, and so forth in this story. In 1588 Toyotomi Hideyoshi, the successor to Oba Nobunaga and predecessor to Shogun Ieyasu Tokugawa, proposed to

[258] Ibid.
[259] Ibid., 33.

build a Great Buddha – out of the "swords, short swords, bows, spears, firearms or other types of arms"[260] that could be found in the possession of the peasantry. This edict, passed ostensibly for spiritual reasons—while also facilitating taxation and reducing the risk of uprisings—had the predictable effect of increasing the ease with which the peasantry remained subjugated.

> Hidéyoshi had deprived the peasants of their weapons. Iéyasu Tokugawa [the next ruler] began to deprive them of their self respect. If a peasant offended a samurai he might be cut down on the spot by the samurai's sword… The two swords thrust through the samurai's belt remained the symbol of his authority which the lower orders had no choice but to recognize.[261]

In this respect, firearms were not only a weapon that could be used to resist taxation or foment uprisings, but were a weapon ideally suited to these tasks since they required little training and could threaten the most skilled samurai. Firearms have often been called the 'great equalizer.' It is probably not a stretch to speculate that some of the peasants interpreted the firearm in a similar manner.

The Shogunate

The third relevant social group was the Shogunate, or central authority. I will avoid exploring in detail, for want of space, the Shogunate's nuanced and changing interpretation of the meaning of firearms. Suffice it to enumerate the principal actions of the Shogunate pertaining to guns and situate this in context of the class and political conflicts already mentioned.

As mentioned, Toyotomi Hideyoshi reduced demand for firearms in 1588 by the straightforward tactic of restricting ownership rights. Beginning in 1607, though, Tokugawa Ieyasu began squeezing the supply side of the gun economy. Ieyasu

[260] Turnbull. *The Samurai: A Military History*, 180.
[261] Ibid., 253.

promoted the four leading gunsmiths of Nagahama to samurai, symbolically giving them their swords in the first stroke against the product of their craft. He then ordered that all gunsmiths relocate to Nagahama and produce guns only for orders that were approved by the Shogunate. Each was authorized to earn an annual salary, to make up for the minimal orders allowed by the government. Over time the gunsmithing community dwindled and the government's monopoly on firearms became more complete. By 1700 the last bastion of relatively autonomous gun production, in Sakai, effectively came to an end. Nonetheless, throughout the Tokugawa period the Shogunate required each lord to have a number of soldiers trained and armed to fight in the event of a war, with about 10% of them equipped with firearms.[262]

The extent to which the Shogunate shared or was influenced by the Samurai's distaste for guns is hard to discern. Irrespective of this influence, though, the Shogunate was in the same business as most monarchical rulers: consolidating the class and political structure by reducing the peasants' access to weapons. King Henry VIII, for example, had declared edicts that greatly restricted ownership of guns. These laws, however, were repeatedly revoked when war with France broke out (in 1543 and again in 1557), and the imperative to defend the nation overwhelmed the desire to consolidate power. Fortunately for the Shogunate, no belligerent neighbors threatened Japan's gun control policies. Ieyasu Tokugawa may or may not have shared the samurai's interpretation of the matchlock, but he most likely did see it as another weapon that the peasantry could do without, and the samurai had no need, nor desire, for.

Based on this sketch, the constructivist scholar would look to Japan's reversion to the sword as a classic example in which different social groups had very different

[262] Chase. *Firearms: A Global History to 1700*, 195.

interpretations of the meaning, use, and desirability of a technology. Because the government and the ruling class both shared an interpretation of firearms that favored their eradication from common use and saw no reason to devote extensive resources to further innovation, it is not a surprise that firearms fell into disuse.

But why did Japan's social construction of firearms diverge so much from the experience of every other country with an advanced firearms industry? Was Japan's uncommonly large samurai population, which as a proportion of the population was approximately ten times greater than feudal Europe's warrior class, a sufficient explanation for Japan's divergent historical outcome? Or did endogenous tendencies to perpetuate the "feudal system," which surely existed in other European nations, find fuller expression in Japan because of their isolation from hostile neighbors? Had Henry VIII not repeatedly found himself at war with France, might guns have been more rare in England? The last period of this story offers an answer, by introducing the set of actors frequently neglected by micro-constructivist analysis: the rival actors in the larger competitive system. In other words, sociotechnical adaptationism is less appropriate during this middle period because of the absence of its defining context: military competition.

Japan's Ambivalent Modernization: 1853-present

Two hundred and fifty years of Japanese isolationism ended on July 8, 1853. On what was otherwise a calm afternoon, four "black ships of evil"[263] (*korofune*) spewing black smoke and incomprehensibly moving without sails steamed into Edo (now Tokyo) harbor. Swarms of little Japanese guardboats surrounded the steamers and attempted to board. But Commodore Perry had no intention of being pushed around. He repelled these invaders with ease.

Commodore Perry, with his 'evil' ships, stayed in harbor for ten days, implicitly threatening bombardment and blockade, awaiting such a time that he could deliver his diplomatically worded ultimatum to an imperial official. At this time Japan had no navy, and only meager coastal defenses; Edo in particular was critically dependent on naval trade from Ōsaka for food. In fact, during Perry's brief stay rice shipments stopped from fear, despite the absence of a blockade.[264]

Commodore Perry informed the Japanese officials that he would return next spring to receive their response. "With all four vessels?" the interpreter asked. "Probably more," Perry replied.[265] And the rest, as they say, is history. Perry returned, the Shogunate capitulated – but only so long as the Japanese had to. Rapid adoption of Western technologies and institutions, helped along by a civil war, and the overthrow of the now obsolete samurai class, all contributed to Japan regaining its sovereignty and superiority. Fifty years later Japan had industrialized and Westernized its military to such an extent that it had the honor of being the first non-Western power to decisively defeat a Western power (Russia) in a large military

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[263]Baruma, Ian. 2004. *Inventing Japan 1853-1964*: Random House;Japanese Spirit, Western Things. 2003. *The Economist*, 10/07/2003

[264] Samson, George. 1963. *A History of Japan 1615-1867*. Stanford: Stanford University Press, 234.

[265] Veit, C. 2005. *Mathew Perry & The Opening of Japan*. On Deck! Navy & Marine Living History Association, 2004 [accessed 4-02-2005 2005]. Available from http://www.navyandmarine.org/ondeck/.

conflict during the modern period. After another forty years, Japan, allied with Germany and other axis powers, posed a serious challenge to British, French, Russian, and American interests. Sixty years following its unconditional surrender in WWII, Japan stands as the world's second most powerful economy.

The moment of Perry's visit, I argue, was a critical juncture in Japan's evolution which neither a constructivist nor an adaptationist approach can fully explain.

To constructivist scholarship, the unanswerable question is: Why did Commodore Perry's visit result in such a dramatic 'reinterpretation' of the meaning of Western technologies? Why were Perry's rhetorical strategies effective, when earlier (less belligerent) visits were ignored? And as will be shown, what use is it describing the various social groups when, once they achieve power, all embrace the same, modernist and realist interpretation of technology? How did 'Perry' have such rhetorical power to radically alter the deeply rooted Japanese interpretations of their technologies?

To adaptationists, the principal challenge is not to explain *why* Japan finally embraced firearms (and industrial technologies and Western institutions), but *how*. Firearms (and other Western technologies) did not diffuse through Japanese culture as a result of individualist rational actors maximizing their military power or economic productivity. Rather, a very complex process of social upheaval and cultural re-imagination was required. To properly understand the rate and pattern of 'diffusion' and development, one must consider how different social groups perceived the technology, what power and options those groups had, and how the social renegotiation transpired.

Foreigners on the Horizon 1750-1853

By the late 1700s an increasing amount of foreign attention was directed towards Japanese shores. The Dutch had long had relations with Japan, albeit confined to an artificial island in Nagasaki harbor (the only port accorded to foreign visitors seeking an audience). Russians, in particular, increasingly demanded attention. In 1804 an ambassador for the Tsar, Vasilii Rezanov, sailed into Nagasaki harbor aboard a warship. There he was politely delayed for five months, only to be told thereafter to leave. The Russian government accepted this and subsequent rebuffs, but Rezanov did not. Rezanov organized some raids in the name of Russia (though without Russia's knowledge) to revenge his wounded pride. The Japanese government (or Bakufu) responded to these incursions by strengthening defenses and preparing for a possible military confrontation with Russia. A later visit by a Russian cruiser resulted in the kidnapping of the unsuspecting Russian captain.[266] Finally, in 1808 the HMS Phaeton, "a major British warship then cruising Asian waters in search of Napoleonic prey, entered Nagasaki harbor,"[267] and demanded provisions. This demand, unmet, escalated into violence, and coupled with the incursions of a Russian raider in the north, "established a new sense among the observant that Tokugawa Japan was exposed as never before to foreign danger."[268]

Foreign ships continued to visit Japanese ports, despite the seclusion policy, leading to the 1825 "no second thought" expulsion decree, which stated simply that all foreign vessels were to be attacked, irrespective of their situation. This policy continued until 1842, when Japanese leaders learned of the disastrous results of the

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[266] Sansom, George. 1963. *A History of Japan 1615-1867*. Stanford: Stanford University Press
[267] Totman, Conrad. 2000. *A History of Japan*: Blackwell Publishing, 279.
[268] Ibid., 279.

Opium War for the Chinese. This moment forced many Japanese leaders to reflect on their own vulnerability, since if European powers could defeat the much larger China, surely they posed a threat to Japan's sovereignty. The seclusion policy was then tempered so as to allow foreign ships to be provided supplies, lest a hostile act incur the wrath of a foreign power. Furthermore, coastal defenses were once more strengthened, and "two companies of infantry and artillery were equipped and trained in Western fashion."[269] These military preparations reflected,

> a policy consensus:. . . in principle bakufu leaders wished to restore the [no second thought] policy of 1825, but doing so must await the construction of sufficient coastal defenses. . . . Despite much noisy resolve, little actual defense strengthening occurred.[270]

Thus, Japan was already moving, albeit at a slow rate, to prepare itself for confrontation with the West, when Commodore Perry so rudely steamed in. It was Perry's visit, however, which posed the problem in its full unavoidable seriousness: foreigners were through with playing diplomatic waiting games and living on artificial islands, and they had the military capabilities to resolve these frustrations. It is for good reason that at least two serious Japanese histories, "Japan Before Perry"[271] and "Japan Since Perry"[272], use Perry's name as a historical referent in the title. Japan's foreign policy options following the Commodore's visit were basically reduced to a stark binary: capitulate or suffer the consequences.

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[269] Sansom. *A History of Japan 1615-1867*, 228.
[270] Ibid., 229.
[271] Totman, Conrad. 1982. *Japan Before Perry*: University of California Press
[272] Yanaga, Chitoshi. 1975. *Japan Since Perry*: Greenwood Publishing Group

A Nation in Flux: 1853-1868

Following Perry's departure the Shogunate's chief councilor, Abe Masahiro, invited the daimyo (provincial) leaders to present their perspectives on Perry's demands. The debate ranged between,

> . . . those who advocated the continuation of the traditional policy of seclusion and those who argued that Japan had no choice but to accept Perry's demand for the opening of the country. Both sides held up the example of China as a warning.[273]

In the end the compromise solution was to cede to Perry's demands, but to continue strengthening the nation with the intent of someday reasserting trade sovereignty and seclusion. Orders went out to encourage the daimyos to invest in modern weaponry, through importation and attempts at indigenous manufacture. Foreign military advisors were invited.

But for every step towards the West, the Shogun was criticized for his acquiescence, especially by those daimyos exposed to the West and with large samurai populations, such as Chōshū and Satsuma. Intermittent conflict with foreigners increased, resulting in the British bombardment of the capital of Satsuma in 1863 as retaliation for the death of some British soldiers. A few weeks later, forts in neighboring Chōshū fired at Western ships, an action that, in the incessant attack-retaliate negotiations of military conflict, resulted in a large Western fleet returning a year later to destroy those belligerent forts. The western daimyos henceforth avoided direct conflict with foreigners, and instead sought ways of overthrowing the Shogunate and recapturing Japanese foreign policy.[274]

In 1864 some samurai from Chōshū unsuccessfully staged a coup against an increasingly weak, divided government, one that was seen as being too compliant with

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[273] Hoare, J. E. 1994. *Japan's Treaty Ports and Foreign Settlements - The Uninvited Guests 1858-1899*: Japan Library, 3.
[274] Totman. *A History of Japan*

foreigners. In consequence senior officials ordered a military expedition to Chōshū to support the local leaders in punishing those samurai responsible for the attempted coup. Only a few months after the retaliatory expedition had left, though, Chōshū's provincial government was overthrown by the broadly based anti-foreigner, anti-Bakufu forces in Chōshū. This new government was able to move beyond naïve notions of winning a civil war solely with samurai tactics. They reorganized their daimyo along more effective lines, importing western rifles and ships, and, of particular note, they radically broke from 250 years of tradition by enlisting non-samurai into their military forces.[275]

The Bakufu, in order to respond to the overt hostility of one of Japan's principal daimyos, looked to France for military assistance and advice. In 1866 the Bakufu launched another attack on Chōshū which failed on account of a secret Chōshū-Satsuma (Sat-Cho) alliance, and Chōshū's impressive military modernization. Both the Sat-Cho alliance and the Bakufu now, ironically, prioritized military modernization in anticipation of a conflict nominally about (anti)foreign policy:

> Bakufu leaders pursued radical internal reforms to modernize their armed forces and reorganize their political structure along the lines of a centralized, European-style regime. Meanwhile Sat-Cho leaders busily purchased weapons, trained troops, and deepened their ties to British merchants and diplomats while adhering to the rhetoric [to "Revere the Emperor, Expel the Barbarian"] because it elicited [samurai] support and embarrassed Bakufu leaders. [276]

Several charged months passed, culminating in the advance of Sat-Cho forces in 1868. After a major battle near Kyoto, the shogun surrendered, and the Sat-Cho alliance began gradually subduing various pockets of resistance. The young Emperor Meiji served as a puppet for the new leadership, and an essential rhetorical device for

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[275] Sims, Richard. 2001. *Japanese Political History since the Meiji Renovation 1868-2000*. New York: Palgrave, 9.
[276] Totman. *A History of Japan*, 286.

convincing and unifying a proud and traditional people to accept the radical changes ahead. And so began the "Meiji Restoration"

Meiji Restoration - Rich Country, Strong Army: 1868-[277]

Many drastic changes occurred during the Meiji Restoration, but the change most pertinent to our question concern's the role of the samurai. Initially many leaders from Chōshū were advocates of continuing their highly effective "mixed farmer-samurai militias." However, a political assassination and the vested interests of various leaders from Satsuma (from where one quarter of the population was samurai) weighed decisively against conscription and modernization of the military. Nonetheless, Yamagata Aritomo, a samurai of Chōshū and influential reformer of the army, had traveled to Europe where he became convinced of the necessity to adopt a modern conscript-based army. By 1873, despite the political intrigues of a few years prior, the arguments favoring conscription and modernization overwhelmed the opposition. Thus, the Chōshū and Satsuma samurai who had helped win the civil war would fail to return Japan to a class-based feudal order. These Samurai failed, or were betrayed, such that

> . . . by 1876, less than a decade after the restoration coup, the economic privileges of the samurai were wiped out entirely. The coup leaders expropriated an entire social class, the semi-aristocratic elite from which they came… The new rulers had other uses in mind for [the samurai's allowances.] The samurai gave back relatively little value for their high costs. Their ranks included many talented people sitting idle. Their time-honored military skills, focused on swords and archery, were useless. Thus the samurai's stipends were basically welfare for the well-born. . . . [The samurai's] annual incomes fell by anywhere from 10 to

[277] For one excellent text which builds off this Japanese expression, see:
Samuels, Richard J. 1994. *'Rich Nation, Strong Army' - National Security and the Technological Transformation of Japan*. Ithaca: Cornell University Press. Note that Samuels emphasizes how economic strength leads to military power, an argument which resonates with sociotechnical evolutionism.

> 75 percent. They further lost pride and prestige: The right to wear swords was denied to all but soldiers and policemen.[278]

This 'betrayal' by the leaders of the coup that the samurai had supported led, unsurprisingly, to a rebellion. In 1877, outraged by the law forbidding samurai to wear their two swords and the related socio-economic changes, 40 000 samurai rose up in the 'Satsuma Rebellion.' They marched north toward the government's conscript army of 65 000. They were armed, writes an American teacher living in Japan in 1877, with,

> . . . 'keen double-handed swords of feudal times, and with daggers and spears. It seemed to be their opinion that patrician samurai could rush into close quarter with the *heimin* [peasant soldiers] and easily rout them,' even though the *heimin* were equipped with rebuilt matchlocks and modern French rifles.[279]

The two armies faced each other in a manner that was reminiscent of Nagashino, and comparably devastating. For, "a full-scale battle of guns against swords can have only one outcome… even as the swords flashed, the air was thick with the 322 000 rounds of ammunition and the 1 000 artillery shells the government averaged each day."[280]

The simplistic contrast between the modern governmental conscript army and the sword-wielding samurai rebellion is, of course, partly a romantic cliché. The rebels were not so tactically ideological as to not include firearms in their logistics planning. Saigo Takamori, the leader of the Satsuma Rebellion, was also, in fact, the former commander of the Meiji army. Nonetheless, the cliché is deserving because, for want of a sufficient ammunition supply and guns that were inoperative in rain, the rebellion was fought principally with samurai steel.[281]

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[278] Gordon, Andrew. 2003. *The Modern History of Japan: From Tokugawa Times to the Present*. Oxford: Oxford University Press, 64.
[279] Quoted in Perrin. *Giving Up the Gun - Japan's Reversion to the Sword, 1543-1879*, 73.
[280] Ibid., 76.
[281] Ravina, Mark. 2004. *The Last Samurai - The Life and Battles of Saigo Takamori*. Hoboken: John Wiley & Sons.

The defeat of the Satsuma Rebellion brought closure to the great debate started 24 years before. Driven by the need to defend itself against foreign encroachment, Japan had, in fits and starts, finally embraced modernization. The last serious opposition to the import of Western techniques and technologies had been silenced, to no small extent because of those very techniques and technologies. The Meiji government, emboldened and empowered by their victory, could pursue the social transformations needed to strengthen the country. A radical program of,

> . . . political consolidation, mass mobilization, military strengthening, economic development, and resource exploitation [was initiated] that began transforming Japan into an industrial society of the sort that western Europe and North America were also becoming.[282]

Convergent Interpretations of Technology

A sociotechnical evolutionist agrees with the constructivists that humans are capable of imposing a range of interpretations on a specific artifact, such as firearms. During the Meiji Restoration, the Japanese exhibited this breadth: some perceived Western technologies to be repugnant manifestations of the inferior barbarians, some perceived them to be repugnant but effective under the circumstances, and a small group of Japanese admired Western technologies. A sociotechnical evolutionist, however, also agrees with the adaptationists that under circumstances of intense competition the interpretations will be constrained by selection processes (and vicarious selection). These interpretations will converge by two processes: 1) vicarious selection, in which actors internalize (learn about) the larger competitive pressures and alter their perceptions so as to better proliferate; and 2) adverse selection by the larger competitive pressures, that is, the loss of power or death.

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[282] Totman. *A History of Japan*.

Vicarious and Direct Selection. Historian Andrew Gordon tells the famous story of Sakamoto Ryoma's conversion to embracing Western technologies. In it we can see an allegory for how those Japanese most hostile to Western intrusions changed their interpretations of Western technology.

> Sakamoto charged into the residence of a bakufu official… With sword drawn, he stood intent on killing this man, who was modernizing the Tokugawa navy along Western lines. His target, Katsu Kaishu, convinced the would-be assassin to first hear him out. In the course of an afternoon Katsu saved his own life and persuaded Sakamoto that modernizing reforms were *inevitable*. Over time, people like Sakamoto developed a profound understanding of Western ideas, institutions, and technologies that would become deeply rooted in Japan.[283]

Sakamoto Ryoma later helped create the secret alliance between Satsuma and Chōshū, and helped supply guns and warships to the revolutionaries.

Sakamoto Ryoma's conversion resonates with a process occurring throughout Japan. Although many Japanese who were hostile to Western peoples and technologies,

> . . . set off on their political path with crude and hopeless notions of standing up to foreign gunboats with razor-sharp swords and expelling the barbarians immediately, many [of them] quickly tempered their extremism with practical experience.[284]

What does historian Andrew Gordon mean when he says that Sakamoto Ryoma, and presumably the many other anti-Western Japanese, were persuaded "that modernizing reforms were inevitable"? We have in this historical moment a situation that cannot be fully understood by either a constructivist or an adaptationist theory of technology, alone. An adaptationist could explain why Western technologies were accepted (because they were superior), but not why they took so long to be accepted, nor could an adaptationist describe the cultural changes prior to this acceptance. A constructivist, on the other hand, could explain why different actors had different

[283] Gordon. *The Modern History of Japan: From Tokugawa Times to the Present*, 53. Italics mine.
[284] Ibid., 53.

perceptions of Western technology, but not why Katsu Kaishu and the other reformers were so rhetorically effective in their appeal to the inevitability of some Westernization. A unified sociotechnical evolutionist perspective, however, can bring these two theoretical approaches together. Different actors had the perceptions that they had for the reasons that the constructivists describe, but because non-Western technologies were mal-adaptive under military competition against foreign powers, these actors were capable of learning (internalizing) the likely consequences (vicarious selection) of continued adoption of non-Western military technologies, and *decided* against the fate that increasingly loomed over China and other Asian powers. This decision set, though, was constrained by military selection to only three real long term possibilities: modernize, lose sovereignty or die.

Social groups rarely stubbornly stick with their interpretation of technology until economic or military competitors defeat them. Rather, most humans build an internal representation of higher level selection pressures (as Gordon's quote suggests, they gained "practical experience"), and alter their behavior accordingly. When Katsu Kaishu tells Sakamoto Ryoma, his would-be assassin, that "modernizing reforms are inevitable," he is actually saying that the selection pressures are so strong against all other politico-economic trajectories that those who follow them will be eliminated (through bankruptcy, lost sovereignty, or death). Sakamoto, wisely, learns from this encounter, recognizing Katsu Kaishu's description of the higher level selection pressures to be accurate, and modifies his own behavior and strategy accordingly.

Military Selection. In this case study there are few moments when rivalrous interpretations of technology compete directly, and military-economic selection "decides" which interpretation should proliferate. In most cases the actors involved were smart[285] enough to recognize when they were defeated, and adapted accordingly. The Shogunate's response to Perry is one such example in which vicarious selection preempted direct selection, as is the Sat-Cho revolutionary leaders 'betrayal' of the samurai, and Sakamoto's aborted assassination attempt. The Satsuma rebellion, if we endorse the romantic interpretation in which samurai made one last attempt to reassert the traditional Japanese way of life, is one of the few cases of direct military-economic selection.

Throughout the civil wars that characterized the Meiji Restoration there were a number of battles in which one side employed obsolete tactics and technologies. One feared group of swordsmen who defended the Shogunate, the Shinsengumi, suffered a major loss against a modern-equipped Satsuma army during a battle in Fushimi. During this battle the vice commander, Hijikata, ordered "a charge with drawn swords because 'the outcome of battle cannot be decided by gunfire.' The Satsuma gunners belied Hijikata's outmoded ideas about war."[286]

After the Shinsengumi retreated, a visiting ally enquired into the battle at Fushimi, to which Hijikata "is said to have replied with a grim smile, 'Swords and spears will no longer be of any use in battle. They are simply no match for guns.'"[287] Soon thereafter Hijikata purchased modern breech-loading rifles for his men.

This case illustrates direct selection against a mal-adaptive military confrontation. Had the Shinsengumi not retreated, we can expect that their order

[285] Had sufficient capacity to represent higher level selection pressures.
[286] Hillsborough, R. 2005. *Shinsengumi: The Shogun's Last Samurai Corps*. North Clarendon, VT: Tuttle Publishing, 142.
[287] Ibid., 143.

would have completely perished. As this case unfolded, like most, the Shinsengumi learned from this experience, and adapted. Thus, though most change and adaptation may be caused by vicarious selection (that is, people making informed decisions), this change cannot be understood without an appreciation for the direct selection that motivates it.

Sociotechnical Evolution

Artifacts do not evolve in isolated testing rooms, but embroiled in a messy world of competing interactors, be they clans, nations, or trade companies. Furthermore, these social groups are not simply an agglomeration of individuals, but are highly structured networks of humans, ideas and technologies. Sociotechnical evolution is messy. So is biological evolution. Just because animals survive or die based on a million contingent events doesn't mean that, over long enough time and space scales, the slight advantages conveyed by mildly adaptive traits won't proliferate. Likewise in sociotechnical evolution. Rarely in history is such a stark technological inequality encountered as when Commodore Perry first visited Japan—basically, this situation only occurs when one sociotechnical system interacts with another for the first time or after prolonged separation. These inequalities resolve themselves painfully quickly, through either rapid adaptation (as occurred in Japan) or invasion (as with the west-ward expansion of the American colonies).

Did firearms, then, convey such an irresistible military-economic advantage sociotechnical systems that they were inevitable? Probably. But not necessarily so. We can speculate on how Japan could have modernized its navy while leaving land warfare to the samurai. But how possible is this? Very often certain technologies require other changes in society, polity, or economy in order to be effectively used. A modern Japanese navy would require an industrial economy. An industrial economy,

however, does not operate very efficiently with feudal social relations and a large, unproductive, warrior class. This massive inefficiency, what technology historian Thomas Hughes would call a 'reverse salient,'[288] is tempting to change. And at some point, either the willingness and power of the reformers will prevail (vicarious selection) or the traditionalist system will be dominated and reconfigured by more powerful external powers, as took place in other Asian powers. In the case of Japan, the cost-benefit calculation of most actors changed at the point when four "black ships of evil mien" steamed in, threatened to starve the Shogun's capital, and made humiliatingly clear the new military-economic selection environment facing the Japanese.

Firearms did not 'beat' swords. Swords were a component of a vast sociotechnical interactor which included expensive samurai and feudal systems of production and governance. This complex was seriously maladaptive in the context of competitive industrializing nation-states. However, it may be that swords are so closely tied to feudal systems and firearms with modern industrialized systems that this simplification is symbolically accurate. Selection was probably favoring industrialization, increased social mobility, empowerment of some classes (capitalist classes in particular), larger polities (to achieve economies of scale in fiscal and defense matters), strong nationalist ideologies, and so forth. Each of these may have been as important as the presence of firearms, and perhaps some more. Alas, selectionism is less easy to observe, and hence less compelling, when operating on political systems as compared to military systems. A cavalry charge into well disciplined infantry illustrates immediately the selection pressures. A corrupt political

[288] Hughes. *Networks of Power - Electrification in Western Society, 1880-1930*.

system slowly sucking the efficiency from a sociotechnical interactor is not as compelling of a selectionist story. But probably just as important.

In this way we could speculate about how constrained, or how inevitable, is sociotechnical evolution. In some cases, where selection pressures are weak or there are many adaptive possibilities, evolution may be highly contingent and variable. At other times, when the converse is true, there may be effectively only one evolutionary path. In the case of Japan, it might have been possible to maintain the ban of firearms. But it doesn't seem possible that the samurai could have maintained their way of life, because that would entail maintaining Japan's feudal social system. In this way, Katsu and Sakamoto may have been right to believe that modernizing reforms were inevitable.

Noel Perrin, in his conclusion, draws some broader lessons concerning the relationship of people to technology:

> The clock that had been turned backward turned forward again with almost incredible speed. … Viewed from the nuclear present, [Japan's] two hundred and fifty years of technological retrogression may seem to have no great significance, except as a historical curiosity, and perhaps as proof that a **deliberate turning back is in fact possible in a civilized society.** … The Japanese experience …proves[s]… that a no-growth economy is perfectly compatible with prosperous and civilized life…[and] that human beings are less passive victims of their own knowledge and skills than most men in the West suppose. …[Many] talk as if progress – however one defines that elusive concept – were something semidivine, **an inexorable force outside human control.** And, of course, it isn't. It is something we can guide, and direct, and even stop.[289]

But the lesson from the Japanese experience is more nuanced than simply that a society can guide its technological course; Perrin, in his rush to reassure humanity that we can still shape our destiny, like many constructivists, generalizes from a

[289] Perrin. *Giving Up the Gun - Japan's Reversion to the Sword, 1543-1879*, 91-92. Bold mine.

limited case study and analytical frame. Perrin emphasizes the turning "back of the clock." But what made the clock suddenly wind forward, making up for two-hundred and fifty years of technological stagnation in fifty?

No one can dispute that humans can interpret, challenge, 'hack,' and reimagine their technologies in the short run, but in the long run, if larger selection pressures are present, then all this interpretive flexibility is just so much variation to be *selected* from. An analyst cannot understand an evolutionary system without having a good understanding of both the variation possible (or scope of interpretive flexibility) AND the strength and character of the selection pressures. The full lesson from the Japanese experience is that: a deliberate turning back is in fact possible in a civilized society ***only if*** *external selection pressures are weak or non-existent.* 'Progress' is something we can guide, and direct, and even stop, *if, like island Japan, we can insulate ourselves from other military-economic competitors.*

In a review of Noel Perrin's book, the esteemed historian of Japan, Conrad Totman, expresses this same point, though without reference to the theoretical implications for the study of technology. Totman writes that:

> Guns went out of style *because war ended*. Had it continued, the use of guns would have continued. . . . By treating the disuse of firearms as an act of will rather than a byproduct of other developments, Perrin draws questionable conclusions about the lesson for our day. He wants us to learn that just as Tokugawa Japan guided, directed, and stopped 'progress,' so we today can 'choose to forget,' and by such a resolute act of will undo the whole process of thermonuclear weapons proliferation. What the Tokougawa experience really teaches us, however, is a more sobering lesson—namely, that the elimination of firearms use required the prior elimination of the *sociopolitical conditions promoting it*.[290]

[290] Totman, Conrad. 1980. Review of Giving Up the Gun. *The Journal of Asian Studies* 39 (3):599-601. Italics mine.

Conclusion

Who—if anyone—controls technological change?

The answer, of course, is that it depends. From the point of view of sociotechnical evolutionism, the degree of agency depends on the character and intensity of selection, and the character of variation. Neither extreme theoretical position, that of the radical social constructivists or the naïve technological determinists, provides a satisfactory answer. There are contexts, usually found on smaller scales of analysis, in which the claims of the social constructivists are valid: in the absence of path-dependent variation, and of economic and military competition, humans have tremendous interpretive flexibility and choice. There are also contexts, usually found on larger scales of analysis, in which the claims of the technological determinists are accurate: when a large and varied population of interactors is competing economically and/or militarily, humans have little substantive power over their collective destiny.

A frequent justification for constructivist scholarship is that it shows how "there is no one inevitable logic of development. There is choice."[291] A common critique of deterministic scholarship is that it "leaves little room for individual agency."[292] Of course, there is always some choice. But criticizing and validating social theories based on apriori criteria of acceptable allowances of agency is misguided. We should not conflate our theoretical priors with our empirical inferences. Rather than judging social theories by the minimum degree of human agency that they allow, I believe that we should evaluate theories based on how well they explain their subject of study. Assuming that individuals "have choice" and

[291] Pinch. The Social Construction of Technology: A review, 34.
[292] Van de Walle, Nicolas. 2005. Democracy and Redistribution (review). *Journal of Interdisciplinary History* 35 (4):625.

assuming that humans have none are equally futile; we should be exploring the hard question of how much and what kinds of agency humans have in different circumstances and why.

Yes, there is always some choice. But in reiterating the constructivist message uncritically, we risk making technological control seem too easy, and we fail to come to terms with the powerful competitive forces shaping history. Our divided world order is aggravating a number of dangerous processes, including the rapid consumption of fossil fuels, disappearing rainforest and biodiversity, global warming, the failure to enfranchise and secure billions of people, increasing inequality, insecure nuclear stockpiles, astoundingly wasteful expenditures on the military, and rapid profit-driven development of unpredictable technologies. The possibility of a global man-made catastrophe is not small.

Technological determinists often commit the mirror intellectual fault to assuming agency: they assume none. For too long economists theorized their markets to be independent of political institutions and social norms. Likewise, political "realists" underestimate the importance of trans-national actors and norms, and too easily dismiss the dream of a global order that could rein in dangerous military rivalries. Our world is poised in a historically unprecedented position, both for its danger and its promise. Through improving communication and transportation technologies, and a growing global social web, we are increasingly capable of global collective action. If particular economic externalities are identified as the source of a global problem, it is conceivable that our world could legislate the problem away. If military competition is deemed as wasteful and dangerous, it is conceivable that our world could establish a system of collective security, such as the European Union is presently constructing. These choices are not ruled out to us, but nor are they easily within grasp. One important step towards controlling our future is to develop an

understanding of the processes that shape the future, including a full appreciation for the breadth of possible human choice and for the competitive processes that constrain it. As a species we can either react to the forces that push us into arms races and ecological collapse, or we can proactively change those forces.

Appendix A. Theories of Technology Table

School's of Thought in the Study of Technology	Scale of Analysis; Degree of Agency	Micro-Mechanisms	Motives of Actors	Explanatory Strengths	Weaknesses	Exemplary Scholars
Strawman, "Nomothetic", "Hard", or Naïve Technological Determinism	Macro; None	Abstract "laws" of history or agency of "technology".	Irrelevant	N/A	N/A	No one.
Technological Determinism with underspecified micro-mechanism.	Macro; Little	Underspecified: unintended consequences; "rationalization" of all life.	Underspecified	Observes long-term patterns in history; resonates w/ intuition; highlights limits of human agency and danger of technology.	Lacking micro-mechanism; may deter political action;	Winner, Mumford, Jacques Ellul, Heilbroner, Karl Marx, Lynn White, Pelto, Neil Postman
Techno-Utopianism with underspecified micro-mechanism.	Macro; Unspecified, possibly forfeited entirely.	Underspecified: scientific and technological progress; capitalism.	Mixed: knowledge, wealth…	Resonant with economic trends; sells products and avoids revolutions.	Lacking micro-mechanism; may be a product of "a magnificent [capitalist] bribe"	Ray Kurzweil, Nick Bostrom,
Sociotechnical Adaptationism (Sociotechnical Evolution by Economic and Military Selection)	Macro; Only if powerful, and there is little competition.	Competition for Military Power amongst plastic sociotechnical systems.	Survival (requires power)	Provides micro-mechanism for deterministic trends. Identifies constraints on agency.	"Adaptationist story telling"/circular reasoning: explains outcome by imputing adaptiveness.	Jared Diamond, John A. Lynn, Kenneth Chase, Robert Carneiro (less explicitly Mumford and William McNeill)
	Macro; Only if powerful, and there is little competition.	Competition for Profit amongst plastic sociotechnical systems.	Survival (requires profit)			Joel Mokyr, Frank Geels, Geoffrey Hodgson (less explicitly Winner, Mumford, McNeill, and Robert Heilbroner)
Technical Power, Technological Politics	Meso; If actor is powerful.	Inscription of Politics into Artifacts	Contextual	Sensitive to power (in tech construction and use).	Fails to explain historical dynamism: why do the powerful ever lose power?	Langdon Winner, David Noble, Bruno Latour, Richard Sclove

Neo-classical and Evolutionary Economics, and Diffusion Studies	Meso; Only if powerful, and there is little competition.	Consumption and Production, Market Behavior	Profit and Utility	Merits of market; innovation and its diffusion.	Often assumes rationality, and perfect information.	Joel Mokyr, Everett Rogers, David Mowery, Nathan Rosenberg, Geoffrey Hodgson, Joseph Schumpeter
Technological Momentum	Micro-Meso; Constrained by past structures.	Social Interaction with path-dependent cognitive, social, and economic investments.	Contextual	Explains historical constraints on actors (ie. some "structure")	Still fails to explain "autonomous tech", trends, and historical dynamism.	Thomas Hughes, Wiebe Bijker ("technological frame")
Mild Social Construction of Technology, or Historical Contextualism	Micro; Constrained, not clear how.	Social Interaction	Contextual	Realistic; compelling historical narratives; detailed.	Atheoretical: "one damn thing after another"; may dangerously underestimate obduracy of crisis.	Most historians and sociologists of technology: Merrit Roe Smith, Leo Marx, Kline, Bijker Thomas Misa, Ruth Cowan, Bijker
Radical Social Construction of Technology	Micro; Unlimited.	Radical Interpretive Flexibility, Social Interaction	Anything	Emphasizes interpretive flexibility and agency.	Ignores properties of technologies (and thus power, cost, efficiency, etc…)	Trevor Pinch, Steve Woolgar (Mild Constructivists with occasional radical rhetoric: Ronald Kline)

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