Innovation and Its Enemies:
The Economic and Political Roots of Technological Inertia

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Abstract: This paper takes another look at the reasons and effects of technological inertia. Resistance to technological change is often regarded as regressive and socially costly, caused by distributional coalitions defending their turf and preserving their rents. While there can be no doubt that sometimes this is a correct view, the reverse argument can be made that in many cases such resistance represents a logical and possibly even socially beneficial source of stability. The paper makes the distinction between the *institutional* aspects of opposition to technological change (in which the debate regards the rules are laid down and whether the market is permitted to be the arbiter whether a new technique is adopted) and *organizational* opposition in which resistance takes place within given institutions. Because of technological externalities and network effects, technological *systems* tend to be much more resilient and inert than individual technologies, and the more the parts of a system are interdependent, the more difficult it is to make changes in it. The net result is one of path-dependence, in which history is one of the main determinants of technological outcomes.

Introduction

Are the crucial decisions that determine economic growth, even in economies committed to free enterprise economics, made primarily in the marketplace? Markets determine the allocation of existing resources and are believed by most economists to be better at this than any alternative. But how about technologic al change? The bulk of the economics of new technology is concerned with the generation of new knowledge and the problems of appropriability and incentives in the creation of new technology. It rarely asks when and how decisions to adopt new technology are made by firms.

Much as economists might perhaps deplore the fact, the acceptance of innovation is more than an economic phenomenon, and certainly far more than a pure advance in productive knowledge. The concept of competition remains central here, but it is not so much the neoclassical concept of price competition of firms in the marketplace as much as Schumpeter's concept of competition between different techniques struggling to be adopted by existing firms or between different final products slugging it out over the consumer's preferences. At times individual techniques may be identified with a firm, but often techniques struggle for adoption within a *single* organization. How are these decisions made? Why is it that even when a new and superior technology is made available at zero marginal costs, the economy to which it is proposed may choose to reject it?

Economic analysis implicitly assumes that new techniques will be adopted if they pass some kind of Amarket test.@ That is, if they can out-compete existing techniques, by producing a more desirable product and/or producing it more cheaply, new technological ideas will be adopted. This is a simple but powerful Darwinian model of technological evolution, and while many of its more Panglossian implications have been muted in recent years, the idea of the market as an arbiter of which techniques will be adopted is still powerful. Economists in the neo-classical tradition are convinced that, although it is theoretically possible for market selection to come up with non-optimal outcomes, such outcomes are in fact rare.

Non-economists are dissatisfied with this approach.[1] Technological progress, it is felt, is a social phenomenon, which changes almost every variable in society. In this paper, I wish to focus on one particular

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[1]As are some economists. See especially Geoffrey M. Hodgson, *Economics and Evolution: Bringing Life Back into Economics*. Oxford: Polity Press, 1993, ch. 13.

issue, namely that new technologies will fail to be implemented despite their ostensible economic superiority. For this class of problems, artificial distinctions between the Aeconomic sphere@ and the Apolitical sphere@ are doomed, and we will not even attempt them. The idea that seemingly superior inventions are spurned or rejected is hardly new. In 1679, William Petty wrote that

> Although the inventor often times drunk with the opinion of his own merit, thinks all the world will invade and incroach upon him, yet I have observed that the generality of men will scarce be hired to make use of new practices, which themselves have not been thoroughly tried... for as when a new invention is first propounded, in the beginning every man objects, and the poor inventor runs the gantloop of all petulent wits...not one [inventor] of a hundred outlives this torture... and moreover, this commonly is so long a doing that the poor inventor is either dead or disabled by the debts contracted to pursue his design.[2]

[2]William Petty, *A Treatise of Taxes and Contributions*. London: Obadiah Blagrave, 1679, p. 53. I am indebted to Patrick O'Brien for bringing this text to my attention.

In this paper, I plan to pursue a somewhat different issue than the disbelief and friction Petty speaks of, namely the purposeful resistance to new technology. Without an understanding of the political economy of technological change, the historical development of economic growth will remain a mystery. The issue of the receptivity of society to new technological ideas is highly relevant to the experience of underdeveloped countries whose failure to adopt best-practice technologies is often regarded as an integral part of underdevelopment. In the very long run, technological progress in its widest sense remains indispensable to sustainable economic growth. Of course, the failure to adopt a new technology can have many reasons: new technology is often embodied in expensive capital good; it often requires scarce complementary factors such as infrastructural capital or a highly skilled labor force. Yet outright resistance is a widely observed historical phenomenon.[3] The adoption of a wholly new technology is often the target of long debates and public discourse, unlike many other technical and economic choices. The role of persuasion and rhetoric in these decisions is something economists have paid scant attention to, and hence they have not had much success in understanding why, for example, some economies have adopted nuclear power or why some have allowed experimental drugs to be sold and others did not. Furthermore, not all resistance is purely social. There are instances in which the technological Asystem@ resists a novel and improved component because it does not fit the operation of the whole.

In any event, technological inertia in many societies has often been ascribed to irrationality, technophobia, a blind adherence to traditional but outmoded values and customs. In what follows, I hope to establish two basic propositions. One is that inertia is usually a characteristic widely observed in complex systems that follow an evolutionary dynamic. Second, technological inertia is usually the outcome of rational behavior by utility maximizing individuals, and that we do not have to fall back on differences in preferences to explain why some societies are more amenable to technological change than others.

[3]For some historical detail, see Joel Mokyr, "Progress and Inertia in Technological Change," in *Capitalism in Context: Essays in honor of R.M. Hartwell*, edited by John James and Mark Thomas. University of Chicago Press, 1994, pp. 230-54.

Rules and Resistance

To simplify matters, define the adoption of a new technique as a binary process: either it is adopted or it is not. Each individual has a set of idiosyncratic exogenous variables (preferences, age, endowments, education, wealth, etc.) which lead him or her to either Asupport@ or Aobject to@ the innovation. To reach this decision, society follows what I will call an aggregation rule, which maps a vector of n individual preferences into a <0,1> decision. This aggregation rule may be a market process (as would be the case in a pure private economy) but such a rule is a very special case. Any change in technology leads almost inevitably to an improvement in the welfare of some and a deterioration in that of others. To be sure, it is *possible* to think of changes in production technology that are Pareto superior, but in practice such occurrences are extremely rare. The pure market outcome is equivalent to an aggregator which weights preferences by their income. The optimality of the outcome will vary with the income distribution even for the market aggregator. Unless all individuals accept the Averdict@ of the market outcome, the decision whether to adopt an innovation is likely to be resisted by losers through non-market mechanism and political activism.[4] Two recent books dealing with social response to technology, while totally different in tone and background, implore social scientists to pay more attention to the question of resistance to the seemingly inexorable march of new technology.[5] One important distinction should be made

[4]As one author has put it, Aopposition to a technology is a special case of a broader class of political activities usually referred to as >special interest= politics, as opposed to the politics of party identification or patronage.@ See Allan C. Mazur, AControlling Technology@ repr. in Albert Teich, ed., *Technology and the Future*, N.Y., St. Martin=s Press, 1993, p. 217.

[5]Martin Bauer, (ed.). 1995. *Resistance to New Technology*. Cambridge: Cambridge University Press; Kirkpatrick Sale, 1995. *Rebels Against the Future: the Luddites and their War on the Industrial Revolution*. Reading, MA., Addison Wesley.

between the introduction of a totally new invention in the economy in which it originates, and the transfer of existing technology into new places after it has already been practiced and tried elsewhere. In both cases resistance may emerge, but its nature may differ substantially between the two. Either way, however, markets judge techniques by profitability and thus, as a first approximation, by economic efficiency. How, then, does conflict occur?

To start with, different groups in the economy favor different aggregation rules. In the terminology of the new Historical Institutional Analysis, an aggregator is an *institution*, that is, a non-technologically determined constraint on economic behavior.[6] If the market outcome rules in favor of one group, another might find it in its interest to circumvent the market process. Suppose that a new technology T_1 is superior to the old T_0 for some individuals belonging to subset S 0 N, but makes those belonging to s 0 N worse off. In general, then, some welfare aggregator G_S, so that $G_S(T_1) > G_S(T_0)$, and G_s such that $G_s(T_1) < G_s(T_0)$. If the members of S and s could form separate societies, one of them supports adopting T_1 and the other does not. Because they cannot, resistance can be interpreted as the attempt of the members of s to abandon the dictates of the aggregation rule in place (for example, the market) and to impose a different aggregator on the economy such as a regulating or licensing agency.[7] It is possible that the number of members in s is larger than that in its complement $s^{\sim}$. In that case there will be a difference between the market, in which Avotes@ are weighted by expenditures and a democratic process, where each person has one vote.[8] In decisions about technology, at least, there could be a serious inconsistency between democracy and continuous innovation.[9] In other words, unlike the optimism of

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[6]The terminology is borrowed from Avner Greif, AMicro Theory and the Study of Economic Institutions Through Economic History,@ prepared for a symposium on Economic history at the 7th World Congress of the Econometric Society, Tokyo 1995.

[7]Joel Mokyr, "Technological Inertia in Economic History," *Journal of Economic History*, Vol. 52 No. 2 (June 1992), pp. 325-338. Id., "Progress and Inertia in Technological Change" in *Capitalism in Context: Essays in honor of R.M. Hartwell*, edited by John James and Mark Thomas. Chicago: University of Chicago Press, 1995.

[8]It clearly is highly ironic to cite here a prominent Indian businessman, Titoo Ahluwalia as saying that Athe average Indian has two sides to him. There is one side that is a consumer and one that is a voter.@ *Business Week*, Oct. 23, 1995, p. 50.

[9]The notion that democracy endangers technological creativity was particularly embraced by nineteenth century reactionary writers opposed to the extension of the franchise such as Sir Henry Maine who argued that Universal suffrage would have prevented most of the major technological breakthroughs of the Industrial Revolution. See Albert Hirschman,

free market advocates in the Friedman tradition, it may well be that democratic decision processes do not maximize the long-term economic welfare of economies. This dilemma faced by democratic countries which wish to undergo rapid development has long been recognized.[10] Barbara Ward explained that uncontrolled market decisions will create intolerable gaps in income distribution and thus resistance of new technology, and totalitarian dictatorships would implement technologies regardless of cost. ABut in India,@ she adds, Aa balance has always to be struck, the dilemma is never absent.@ Yet in her view this is precisely India's strength, since whatever modernization is introduced is usually based on a consensus and thus unlikely to ignite political explosions.[11]

The Rhetoric of Reaction. Cambridge: Harvard University Press, 1991, pp. 97-100, who adds that the argument was palpably absurd and immediately proven to be so. Yet it is not impossible that democracy could under certain circumstances be *less* hospitable than other political regimes to technological progress.

[10]For an interesting discussion which concludes firmly that Ademocracy entrenches economic freedoms, and in doing so underpins growth,@ see AWhy Voting is Good for You,@ *The Economist*, Aug. 27 1994, pp. 15-17.

[11]Barbara Ward, *India and the West*, New York, W.W. Norton, 1964, p. 150-52. These words were written many years before the experience of the Shah of Iran confirmed her insight.

The reasons why members of S and s prefer different aggregation rules need some elaboration. One issue is that technology may appear *directly* in people=s utility function. Such a concept may appear bizarre to economists, but not so to sociologists or psychologists.[12] For economists, moreover, it has been deemed traditionally uninteresting to ascribe differences in behavior to different utility functions. Historically, however, cultural and religious elements may have had a big influence on technological decision-making.[13] Technology is something profoundly unnatural, as Freud observed in his *Civilization and its Discontents* when he compared it to an artificial limb. Technology is regarded by many writers as something uncontrollable and incomprehensible

[12]In the psychological literature there is a great deal of emphasis on seemingly Airrational@ phenomena such as fear of new technology. Psychological Adiagnosis@ of Acyberphobia@, Atechnophobia@ and even Aneophobia@ [fear of new things] is common. For a thoughtful debunking of this literature, see Martin Bauer, A>Technophobia=: a Misleading Conception of resistance to New Technology@ in Bauer, ed., *Resistance to New Technology*, pp. 87-122.

[13]All technology, as it involves manipulation of nature, is inextricably mixed up with religion, and not just medical and biological research as in our time. For some introductory notes, see Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress*, New York: Oxford University Press, 1990, pp. 170-73, 200-06.

and thus somehow evil in itself. The literature on this issue is rather large and cannot be done justice to here.[14] At this stage, I will assume identical utility functions and attribute the differences in opinion to observable parameters such as differences in information, economic costs, and endowments. Proposed technological changes are expected to benefit one segment of society and harm another; the market may determine one outcome, which could be circumvented by another aggregator.

Formally, we may distinguish between the following decision rules. G_M, which is the pure market aggregator means that the new technology will be adopted by profit-maximizing firms following exclusively the dictates of the market. G_D is a decision rule that designates an *authorized subset* such as representative parliament or a panel of technical experts, a violent mob, a court, or a single dictator, to decide whether to permit and/or support the new technology. G_V is a voting rule, say one-person-one-vote, in which a new technology is voted in or out by some kind of referendum. In most realistic situations the actual decision rule or aggregator which maps individual preferences to the decision space $<0,1>$ is $G = \alpha G_M + \beta G_D + (1-\alpha-\beta)G_V$ where $\alpha+\beta$#1. The pure market outcome occurs only when $\alpha = 1$. The social decision process may thus be viewed as consisting of two stages. First, society determines the political rules of the game, that is, it sets α and β. Then, depending on the aggregator chosen, it determines whether the new technique will be adopted or not. An obvious elaboration of the simple model is that one decision maker may delegate decisions to another: the authorized subset can decide to hand things over to a referendum or leave it up to the market. An election, on the other hand, can appoint a body of people delegated to make the decision or do nothing at all so that the decision to adopt is effectively left to the market. The interpretation of α and β as probabilities or proportions of the Acases@ that are decided in one arena or another thus lends some intuitive meaning to G.

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[14] For a historiographical introduction, see Langdon Winner, *Autonomous Technology*. Cambridge, MA: MIT Press, 1977, pp. 107-34.

A great deal of political and social struggle involves not only the implementation of new technology itself, but the decision rules themselves, as it is reasonably believed that some decision rules favor one interest group more than another. Economists, in particular, are concerned by the size of α, that is, how much of the decision is left to the market and how much will be decided on by other aggregators. In part, the aggregator will be determined by the nature of the product: technological change in public goods and other areas of market failure will be obviously largely outside the market decision process; but there is a huge gray area of private goods where there is room for political action. It may be thought that societies will be more creative and technologically successful the larger α, but this is by no means certain. It may well be that the free market, for reasons of its own, foregoes technological opportunities. For instance, the new technology may require unusually large capital spending or a coordination between existing firms that cannot be materialized without direct intervention. In that case, the government may step in to make up for the market failure. Pre-revolutionary France, especially, saw a great deal of government involvement in trying to encourage French entrepreneurs to accept British techniques.

When the aggregator has been decided upon, as long as $\alpha < 1$, so that -- as is often the case -- some non-market decision is necessary to approve the new technology, opposition occurs within given political structures, such as a courtroom or a parliamentary committee. Of course, many new technologies are too trifling to be the matter of public debate; one hears little of a public outcry over the switch, say, from spark-plugs to fuel injection or from dot-matrix to ink-jet printers. In those cases the decision will normally be delegated to the market. But when there are major technical choices that involve public expenditures, complementary or substitute relations with other technologies, or other types of spillover effects, they will end up being judged by non-market criteria.[15] Similarly, uncertainty of any nature regarding possible externalities, especially when these concern public health and safety, almost invariably lead to a reduction of the market component in the aggregator. In those cases, political lobbying about the new technology is natural. The usual rules of political economy and collective decision-making by interest groups apply, with the additional complications that the introduction of a new technology is by definition a highly uncertain event, involving known and unknown dangers that play no role in, say,

[15]The adoption of fluoridation of drinking water in the United States, the use of insecticide in mosquito abatement, and all matters pertaining to military technology are prime examples of such public technical choices.

political decisions about tariff policy or public work procurements. Moreover, the technical and scientific issues are often highly complex and even a phrasing of the correct *questions* (let alone the answers) is often beyond the intellectual capability of decision makers. Precisely for that reason, there is more reliance on the opinion of Aexperts@ but also, paradoxically, a frequent appeal to emotions, fears, and religious and nationalist sentiments. As litigation becomes increasingly important, technological decisions are relegated to courts, and rhetorical imagery and other persuasive tools, from TV ads to neighborhood rallies, become a means by which technological decisions are made. Reliance on technical expertise, a long-standing practice in the West, is weakened by disagreements among experts and even disagreements as to *who* is an expert to begin with.[16]

[16]Dorothy Nelkin has pointed out that the very fact that experts disagree -- more even than the substance of their dis agreement -- leads to protests and demands for more public participation. See Dorothy Nelkin, AScience, Technology and Political Conflict,@ in Dorothy Nelkin, ed., *Controversy: Politics of Technical Decisions*. London: Sage Publications, p. xx.

An anti-technological and conservative bias can be built into a culture, so that the decision-making body becomes technologically reactionary. In this fashion, the technological status quo does not have to fight battles against hopeful innovations over and over again. This cultural bias can be introduced through an education system that fosters conformist values in which traditions are held up in respect and deviancy and rebellion made highly risky.[17] Morris lists the sources of technological reaction in traditional India: there was no organization for the propagation or dissemination of knowledge, and an unbridgeable social barrier between theorists and craftsmen.@[18] Eric L. Jones has argued that the Indian caste system was a deeply conservative and rigidified institutions, in which ascriptiveness is pervasive and personal achievement Ais excluded in principle.@ Jones realizes that a caste system, too, could never be an *absolute* constraint on economic growth, it Amay constitute an infuriating brake, yet it will not be able to switch off a motor located somewhere else in society.@[19] The argument made here is exactly about such brakes; societies with such brakes would develop much slower than those without. Perhaps that is as much as we will ever be able to say about economic growth.

All cases of resistance to technological change can be reduced to those two main typologies: a struggle *over* the decision rules and (if $\alpha < 1$) a struggle *within* them. The political battles over technology have profound implications for economic history. One is, as I have emphasized elsewhere, that technological progress in a given society is by and large a temporary and vulnerable process, with many powerful enemies whose vested interest in the status quo or aversion to change of any kind continuously threaten it.[20] The net result is that changes in technology, the mainspring of economic progress, have been rare and that *stasis* or change at very slow rates has

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[17]Bernard Lewis has pointed out that in the Islamic tradition the term *Bidaa* (innovation) eventually acquired a seriously negative connotation, much like Aheresy@ in the West and that such subtle cultural changes account for much of the technological slow-down of the Islamic Middle East after 1400. Cf. Bernard Lewis, *The Muslim Discovery of Europe*. New York: W.W. Norton, 1982, pp. 229-30. This is not to argue that *any* religion is inherently anti-technological, even in a relative sense. Yet there are many subtle ways in which an entrenched elite can manipulate institutions and culture in order to make any contemplated challenge to their dominance more difficult.

[18]Morris D. Morris, AThe Growth of Large-scale Industry till 1947@, in Dharma Kumar, ed., *The Cambridge Economic History of India* Vol. 2. Cambridge: Cambridge University Press, 1983, p. 563.

[19]Eric L. Jones, *Growth Recurring*. Oxford: Oxford University Press, 1988, pp. 103-06.

[20]Joel Mokyr, "Cardwell's Law and the Political Economy of Technological Progress," *Research Policy*, Vol. 23 (1994), pp. 561-74.

been the rule rather than the exception. It is our own age, and especially the rapid technological change in the Western World, that is the historical aberration. Another implication is that most underdeveloped countries cannot take technology transfer for granted. Even when capital is available and complementary inputs such as skilled labor and infrastructure are present, attempts to transplant technology from one society to another are likely to run into social barriers that economists may find difficult to understand. Before we can delve into the economic and social causes of resistance, we need to place its importance in a theoretical framework.

Inertia and Evolution

Many scholars have recognized that new techniques emerge in a manner that is in some ways analogous to the emergence of new species and variations on existing ones in the evolution of living beings.[21] The choice of techniques is akin to the process of natural selection; natural selection is really a metaphor for an impersonal process in which no concrete entity actually does the selecting. New technologies are similarly selected (although here at least in some cases the selecting is done by conscious individuals making deliberate choices). The market is of course one arena in which this selection takes place; the political sphere is another.

[21] For a recent summary see Joel Mokyr, "Evolution and Technological Change: a new Metaphor for Economic History?" in Robert Fox, ed., *Technological Change*. London: Harwood publishers, 1996, pp. 63-83.

Despite the seemingly unbelievable diversity of life forms, actual phenotypical change is quite unusual and runs into many barriers. The understanding that natural selection is inherently a *conservative* process was first emphasized by Alfred Russel Wallace, who likened natural selection to a governor on a steam engine, essentially a device to correct deviations automatically. The eminent biologist Gregory Bateson who points this out, notes that the rate of evolution is limited by the barrier between phenotypic and genotypic change so that acquired characteristics are not passed on to future generations; by sexual reproduction which guarantees that the DNA blueprint of the new does not conflict too much with that of the old; and by the inherent conservatism of the developing embryo which necessarily involves a convergent process he call epigenesis.[22] System externalities have an equivalent in biology known as "structural constraints." Genetic material is transmitted in "packages" and thus sticks together. The information transmitted from generation to generation does not consist of independent and separately optimizable pieces. A "little understood principle of correlated development" (as Darwin called it) implies that certain features develop not because they increase fitness but because they are correlated with other developments. We now know why this is so: genetic linkage causes genes that are located in close proximity on the chromosome to be inherited. At the same time, evolution tends to be localized and cannot change too much at once. As François Jacob put it in a famous paper, evolution does not so much create as tinker: it works with what is available, odds and ends, and much of it involves therefore minor variations on existing structures.[23] Selection

[22]Gregory Bateson, *Mind and Nature: a Necessary Unity*. New York: Dutton, 1979, pp. 175-76.

[23]See Jacob, "Evolution," p. 1165. Such "minor" variations, however, can have huge consequences on the

could also misfire when a trait leads to what is called "positive feedback traps," that is, selection of a trait because of its success in satisfying the fitness criterion but trapping it at a low level of fitness.[24]

phenotype. As Jacob notes, "small changes modifying the distribution in time and space of the same structures are sufficient to affect deeply the form, the functioning and behavior of the final product" (p. 1165). For a similar view see Stephen Jay Gould, "Is a New and General Theory of Evolution Emerging?", *Paleobiology*, 6(1) (1980), p. 127.

[24] Peter M. Allen and M. Lesser, "Evolutionary Human Systems: Learning, Ignorance and Subjectivity." In P.P. Saviotti and J.S. Metcalfe, eds., *Evolutionary Theories of Economic and Technological Change: Present Status and Future Prospects*, London: Harwood Publishing 1991. An example is the peacock's tail, which helps each peacock in the reproductive game and thus conveys a selective advantage despite the uselessness of the tail in survival-related functions. The same was true for the extinct Irish Elk: its enormous antlers gave its bearers a putative advantage in mating, but they were apparently useless as a defensive tool, and helped in the demise of the species. One can easily think of products that survive because of their success in marketing and advertising despite demonstrable lower quality.

Furthermore, the emergence of new species (speciation), analogous to the emergence of new techniques, is both rare and poorly understood. Although the resistance to change in natural systems is of an entirely different nature than that in technological systems, it too implies a cohesive force that limits the amount and rate of change. As Mayr has recently explained, AJust exactly what controls this cohesion is still largely unknown, but its existence is abundantly documented...during the pre-Cambrian period, when the cohesion of eukaryote genotype was still very loose, seventy or more morphological types (phyla) formed. Throughout evolution there has been a tendency for a progressive Acongealing@ of the genotype so that deviation from a long-established morphological type has become more and more difficult.@ While such genetic cohesion has of course not precluded the well-known adaptive radiations which created different species, these explosions of variety are little more than ad hoc variations on a *bauplan* or structural type.[25] This cohesion, as Mayr emphasizes, while not wholly understood, is essential to the development of the world of living species: the key to success is to strike a compromise between excessive conservatism and excessive malleability. Evolutionary systems, whether biological or other, that are too conservative will end up in complete stasis; too much receptivity to change will result in chaos.[26]

In the economic history of technology we may have been more fortunate. Radically new technological ideas, from antibiotics to nuclear power to telegraphy, have emerged time and again despite the odds against them. Yet the dynamic may be similar: a system which struggles to change against built-in inertia is more likely to change in sudden bursts than in slow, continuous fashion. The idea of Apunctuated equilibria@ in evolutionary change can be projected to historical processes to cast light on the question why so much of historical change occurs in concentrated spurts of intense technological activity such as the British Industrial Revolution.[27] Most recent research in modern evolutionary biology suggests that the dynamic of evolution, too, proceeded in intensive

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[25]Ernst Mayr, *One Long Argument: Charles Darwin and the Genesis of Modern Evolutionary Thought.* Cambridge, MA: Harvard University Press, 1991, pp. 160-61.

[26]For a detailed argument along these lines, see Stuart Kauffman, *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. New York: Oxford University Press, 1995, p. 73.

[27]Joel Mokyr, "Punctuated Equilibria and Technological Progress," *American Economic Review*, Vol. 80, No. 2 (May 1990), pp. 350-54; Joel Mokyr, "Was There a British Industrial Evolution?" In *The Vital One: Essays Presented to Jonathan R.T. Hughes*, edited by Joel Mokyr. Greenwich, CT: JAI Press, 1991 pp. 253-86.

spurts separated by long periods of stasis rather than in linear progressions.[28]

[28]For an accessible summary, see Niles Eldredge, *Reinventing Darwin: The Great Evolutionary Debate.* London: Weidenfeld and Nicholson, 1995.

The analogy with evolutionary biology underlines the rather unlikely nature of continuous technological progress. Stability in the systems of living beings is maintained by what biologists term genetic cohesion. Similarly, technology is subject to *technological cohesion*, basically meaning that on the whole technological systems will be stable and inert. It could be the case, of course, that the agents of change, whether they are mutations in DNA or new ideas occurring to people, are themselves highly nonlinear in their frequency. It is more plausible, however, to assume that changes in Amutagens@ are relatively rare and that mutations occur at more or less uniform rates but are constrained by the inertia and resistance to change within the system. The likelihood of change taking place depends on the outcome of the struggle between novelty, thirsting for a chance to take its place, and the old, fearful of any threat to the status quo. As Wesson (1991, p. 149) has pointed out, "the most important competition is not among individuals and their lineages, but between new forms and old. The old must nearly always win, but the few newcomers that score an upset victory carry away the prize of the future." This paragraph, written as a comment on Darwinian evolution, mirrors the one written decades earlier by Schumpeter (1950, p. 84): "In capitalist reality, as distinguished from its textbook picture, it is not [price] competition which counts but the competition from the new commodity, the new technology... which strikes not at the margins of the profits of the existing firms but at their ... very lives."[29] Schumpeter believed that pure competitive capitalism ensured that cases in which a superior technology would be rejected would be rare, but also understood the fragility of capitalism in democratic society.

In the context of a struggle between the status quo and novelty, the non-linear dynamic of historical evolution becomes more plausible. The technological status quo will create barriers that make it more difficult for new ideas to catch on, and at times may succeed in rigging the decision-making process so that novelty becomes almost impossible. Once these dams are broken, however, the torrent of innovation may be unstoppable, at least for a while. Precisely if the political arguments are not cast in terms of the perceived costs and benefits of the

[29]Robert Wesson, *Beyond Natural Selection*. Cambridge, MA: MIT Press, 1991, p. 149; Joseph A. Schumpeter, *Capitalism, Socialism and Democracy*. 3rd edition. New York: Harper and Row, 1950. p. 84.

new technology itself but rather in terms of the rules that are to be followed in making these decisions, such non-linearities become understandable.

The story becomes considerably more involved but also richer when we regard not only technology but also institutions as subject to evolutionary forces. Douglass C. North has stressed the idea that institutions evolve in that their dynamic can be described by stochastic shocks subject to selective filters, even if not all the implications of this approach were fully explored.[30] What we have, then, is two evolutionary systems, one epistemological (technology) and one political and social (formal institutions, customs, and other informal rules of behavior) that co-evolve over time.[31] An example is the emergence of American industrial capitalism after the Civil War, in which the technology of interchangeable parts and mass production assembly lines implied an enormous growth in the optimal scale of much of the manufacturing. This technology co-evolved with changes in the structure of business institutions, including the emergence of the modern hierarchical business corporation, labor unions, and the growth in efficiency and scope of capital and labor markets.[32] Such a continuous interactive co-evolution means that if a foreign technology were transplanted into a society where the adapted institutions had not evolved jointly, serious incongruities and disruptions could be the result. The consequent resistance to technological change can, in this fashion, be reinterpreted in a wider context.

Markets or Politics?

Although the terminology here is different, the concept of heterogeneous aggregators is closest to the concepts enunciated by Olson in his *Logic of Collective Action* and *Rise and Decline of Nations.* Consider for simplicity an economy that has to make a binary choice whether to adopt T_1 or not. While in a market economy

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[30]See Douglass C. North, *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press, 1990, p. 87.

[31]This idea was suggested to me by Dr. John Kurien of the Center for Development Studies at Thiruvananthapuram. For a further discussion of co-evolution in a biological context see Geerat Vermeij, "The Evolutionary Interaction Among Species" *Annual Reviews of Ecology and Systematics*, 1994. Whereas Vermeij's analysis deals primarily with interaction between two evolving species, there is no reason why his analysis cannot be extended to larger groups. Vermeij himself has repeatedly stressed the isomorphisms he sees between paleobiological and social history. Kauffman, *At Home in the Universe,* p. 217 suspects that Abiological coevolution and technological coevolution ...may be governed by the same or similar fundamental laws.@

[32]Richard R. Nelson, ARecent Evolutionary Theorizing About Economic Change,@ *Journal of Economic Literature*, Vol. XXXIII (March 1995), p. 64.

such decisions are of course made by individuals, in most societies discontinuous and discrete changes in the main technique in use involve to some extent public decision making. Patents have to be issued, environmental impact statements are filed, and in many cases outright licences and support from some public authority are required.[33]

When, then, will opposition to the market as the arbiter of innovations emerge? To start with, assume for the sake of argument simply that all utility functions contain only income as an argument, and that the only effect that the transition from T_0 to T_1 has is to increase the real income of $s^{\sim}$ individuals, to reduce the real income of s individuals such that $3_{s\sim}dY|T_1 > -3_s dY|T_1$. This means that the invention is socially preferable, but the potential for conflict is only resolved if the gainers use part of their augmented incomes to compensate the losers. Compensation would seem at first glance a reasonable way to resolve the problem but in fact rarely occurs directly because of the formidable problems of identifying the losers, measuring the dimensions of their loss and overcoming the problems of moral hazard among losers as well as collective action amongst gainers. All the same, compensation does occur. The welfare and farm support systems in modern Western economies could be interpreted at least in part as mechanisms designed to compensate and placate groups that ended up at the short end of the stick in rapid industrialization and subsequent de-industrialization. If compensation does not occur, the losers will have an interest to band together to try to change the social decision rule from G_M to a rule that is more favorable to them. The way for them to do this is to circumvent the market, in our terms by reducing α and then try to affect the aggregator G_D and/or G_V by political action. It is in this fashion that persuasion and rhetoric enter the story; in a Apure@ market system, they need not enter the debate.

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[33] An example would be the adoption of railroads after the 1830s, which involved varying combinations of private and public decision making in different countries. In Britain, the decision to adopt railways was largely a private decision made in the context of the free market; in other countries the government played a direct entrepreneurial role.

A major reason why people tend to remove the market as the sole arbiter of technological decisions and delegate part of the decision-making process to political bodies is that markets effectively truncate preferences over technology at zero. If one supports a new technique, one can vote Ayes@ by buying the new product or switching to the new technique. By not buying the product or refusing to switch, one can express indifference or dislike, but individuals have no control over what others do even if they feel it might affect them. In markets it is difficult to express a Ano@ vote. Another reason is that so much technology is part of the public sector: transport, public health, infrastructure, and the military require political approval of changes simply because these are sectors in which some form of prior market failure has been observed.

Above all, consumers seem to distrust the free market as an arbiter of new technology just because it is new. Whereas in a technologically static economy there may be no reason to distrust the invisible hand, the informational asymmetries and irreversibilities associated with the generation and adoption of new techniques seem to demand a cool and unbiased arbiter. It is feared that greedy entrepreneurs will sell asbesto-type products to the public and then abscond. Thalidomyde-type of disasters, however small compared with the benefits of advances in medical technology, produce a constant demand for government assurances that new products and techniques are safe. At the same time it needs stressing that not all resistance to technological progress is necessarily conservative and in defense of some technological status quo. Many cases of social resistance to a new technique occur because there are two alternatives to T_0, T_1 and T_2. Left to the market, T_1 will be chosen; if some interest group wishes to use non-market mechanisms to bring about some alternative T_2, it is the *nature* of technological change they wish to influence, not its very existence.[34]

Self-interest, of course, counts too. Economists have used the term Arent-seeking@ for the replacement of market decisions by government control or some other form of collective decision making that benefits a small group or individual. Here we expand the standard definition of rent seeking to include Aloss-avoidance.@ Historically, most of the resistance to new technological change had economic reasons: potential losers set up obstacles to obstruct innovation. The main question is why for some individuals technological change is income-

[34]This is what sets aside the literature of Aalternative@ or Asoft@ technology advocated by Amory Lovins from the shrill and technophobe positions advocated by, say, Ivan Illich and Chellis Glendinning.

reducing. Below I provide a typology of some of the more obvious sources of purely rational resistance to innovation.

a. Unemployment. One obvious reason, widely believed since Ricardo's famous chapter on AMachinery,@ is that labor-saving technological change reduces the demand for undifferentiated labor thus leading to unemployment and a possible decline in wages. As economists have long understood, this statement in and of itself cannot be accepted without working through the general equilibrium properties of an exogenous change in the production function. An invention that replaces workers by machines will have effects on *all* product and factor markets. An increase in the efficiency of production which reduces the price of one good, will increase real income and thus increase demand for other goods; the replaced workers may find employment in other industries, and their real wage may go up or down. In an abstract general equilibrium world, without adjustment costs, in which all workers and productive assets can be costlessly converted from one usage to another, there is no a priori expectation that changes in production technology will necessarily reduce labor income and employment. In the real world, of course, temporary disequilibria can cause hardship to large subgroups of the population. Yet in some of the most widely studied instances, the feared patterns of technological unemployment did not materialize. Nineteenth century Britain did not suffer from a secular increase in structural employment feared by Ricardo and the Luddites alike. In a very different environment, it was widely feared that the mechanization of agriculture in Asia in the 1970s would lead to widespread rural unemployment; this did not occur.[35] Recent studies by labor economists find that the introduction of new technology is on balance associated with positive job *growth*. One such studies flatly declares that Ajob growth and the introduction of new technology appear to be complements rather than substitutes. The Luddites were wrong.@[36]

b. Capital Losses. A different problem occurs when physical capital is of a Aputty-clay@ variety; once shaped, it is difficult to convert to another use. This can be seen in a simple vintage model in which one product is produced

[35]M.J. Campbell, ATechnology and Rural Development: The Social Impact.@ In M.J. Campbell, ed., *New Technology and Rural Development: The Social Impact*. London: Routledge, 1990, p. 26.

[36]David G. Blanchflower and Simon M. Burgess, ANew Technology and Jobs: Comparative Evidence from a two-Country study.@ Presented to the National Academy of Sciences Conference on Technology, Firm Performance and Employment,@ Washington DC May 1995 (version cited dated Dec. 1995), p. 18.

by machines of different efficiency. The lowest ranked machine earns a rent of zero; all other machines earn a rent that is proportional to the difference between the production cost of the least efficient machine in use and their own. The value of the asset can thus be determined by the p.d.v. formula, in which the value of the asset is a function of this difference and *expected* future technological depreciation. A rise in the rate of technological change will reduce the market value of existing machines of older vintage and thus it might be expected that the owners will find a way to avert it if they can.

Yet in practice this happens rarely. The cases in which the owners of physical capital have fought against the introduction of new techniques are comparatively few. The reason must be that while the physical qualities of machines can only rarely be altered, capital goods -- including ownership in patents --can be bought and sold.[37] Thus the owner of a set of machines that become obsolete will take a loss on those machines, but he can always buy into the new technology by buying the new machines that yield the higher profits through lower costs. This explains, for instance, the relatively weak resistance to the introduction of steam engines despite the huge locational rents that were being secured by the owners of water mill sites. Industrialists using water power might have been losing when their mills fell into disuse, but they could make up for those losses by buying into steam technology themselves, which is precisely what happened in Lancashire during the British Industrial Revolution. In

[37]It is critical for this argument that patents do not categorically exclude some existing producers from licensing patents or having them assigned to them. When this happens, it is of course quite likely that existing producers will not be able to jump the new bandwagon. For a survey of how common patent licensing and assignment already was in nineteenth century America, see Naomi Lamoureaux and Kenneth Sokoloff, A Long-term Change in the Organization of Inventive Activity,@ presented at the National Academy of Sciences Colloquium on Science, Technology, and the Economy, Irvine, CA., Oct. 20-22, 1995.

those cases in which capital markets favored some existing producers over others, however, this principle is violated and in such cases resistance is to be expected.[38]

[38]A recent example is provided by Bruland. Norwegian fishermen in the eighteenth century resisted a new technique of multiple lines, which enhanced productivity but whose use was Aconfined to relatively well-off fishermen who could afford to invest in extra equipment and suitable boats.@ See Kristine Bruland, APatterns of resistance to new Technologies in Scandinavia: an Historical Perspectives,@ in Bauer, ed., *Resistance*, p. 131.

c. Non-pecuniary losses. Another source of resistance to technological change is that it changes not just the *level* of average costs, but the overall *shape* of the cost function. While new technology thus reduces overall costs and increases efficiency, it may also change the minimum efficient size of the firm and the entry conditions to the industry. Thus, when the minimum efficient size of firms in the textile industry was hugely increased during the first Industrial Revolution, artisans and small domestic producers were effectively driven out of the industry. In a world without transactions- and information costs and hence Aperfect@ capital markets, the costs of these changes would be mitigated by small producers combining into large firms and exploiting some of the economies of scale. This did occur at a larger scale than is usually appreciated.[39] The so-called Aworkshop system@ in which workers hired space and a piece of equipment in a large building and worked on their own account without hierarchy and discipline was prominent in many industries until deep into the nineteenth century. All the same, during the British Industrial Revolution even before the famous Luddite and Captain Swing disturbances, there were some riots by artisans and self-employed producers threatened by factories.[40]

Workers, moreover, care about such non-pecuniary characteristics of the work-place from safety and noise on the shopfloor to job satisfaction and decision-making authority. If new technology affects these characteristics negatively, workers will resist unless they can be bought off by employers through fully-compensating wage increases or unless they can find new jobs similar to their old ones at zero cost to themselves. During the Industrial Revolution, a particular bone of contention was the attempt by employers to standardize products and reduce the leeway that artisans and domestic workers had in setting the parameters of the product. When the advantages of product standardization led to lower tolerance boundaries on the characteristics of output, from cotton cloth to musket balls, repeated attempts to enforce such standards ran into determined opposition.[41] Beyond that, technological change affects the regional distribution of production and employment, thus forcing

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[39]Gregory Clark, AFactory Discipline,@ *Journal of Economic History*, Vol. 54, No. 1 (March 1994), pp. 132-35. In other societies, too, such workshops occurred early on in the industrialization process. In India, industries such as cotton ginning, rice polishing, and flour milling, entrepreneurs often just provided the machines and their maintenance and charged a fee for processing from the workers. See Morris Morris, AThe Growth of Large-scale Industries,@ p. 675.

[40]Adrian Randall, *Before the Luddites*. Cambridge: Cambridge University Press, 1991.

[41]Ken Alder, *Engineering the Revolution: Arms, Enlightenment, and the Making of Modern France*. Princeton: Princeton University Press, 1996, chs. 4-5.

workers to move from one region to another or from a rural to an urban area. New technology is often felt to destroy traditional communities. For some members of those communities that counts for little whereas others care about it a great deal; thus any kind of aggregator will lead almost inevitably to some subset of the population being dissatisfied.

d- Human Capital. The opportunities for conflict are much wider when we consider human capital.[42] Skills and experience are acquired over a lifetime, but the ability to learn new skills declines over the life cycle.[43] Workers beyond the student or apprentice stage can be expected to resist new techniques insofar that innovation makes their skills obsolete and thus irreversibly reduces their expected life-time earnings. The new technology may be inaccessible to them for more reason than one; factories require a willingness to submit to discipline and hierarchy that the independent artisan was too proud to submit to. It is of no consolation to the older generation that their children may have no difficulty adjusting to the new regime, mastering the new technique and thus improve their material standard of living. Again, the example of the British Industrial Revolution illustrates this point vividly. As the old domestic industries came increasingly under pressure from the more efficient factories, the older artisans by and large refrained from seeking employment in them; the reliance of factories on child and teenage labor was motivated by the ability of youths to learn the skills and adopt the docility required for the factory environment.[44]

[42]In a formal analysis of the emergence of resistance among skilled workers, Krusell and Ríos-Rull ingeniously capture an example of this kind of problem. They model an economy in which all capital is technology-specific human capital, and show that older workers who have invested in a skill that is specific to a technology threatened by obsolescence can be modeled as a "vested interest" for whom it is optimal to try to block the new technology. See Per Krusell and Jose-Victor Ríos-Rull, "Vested Interests in a Positive Theory of Stagnation and Growth." Unpublished manuscript, 1992. For an analysis along similar lines and the important constraint on the effectiveness of such resistance by the openness of the economy, see Thomas J. Holmes and James A. Schmitz, AResistance to New Technology and Trade Between Areas,@ Working paper, Federal Reserve Bank of Minneapolis, 1995.

[43]As *The Economist* put it recently, AWhat grown-up who spent years of childhood learning to tie shoes, to count to ten, to parse Greek or to find triple integrals does not now sigh at having to lipread the baffling instructions for a video recorder or for Windows 95? Almost every generation gets overtaken in some department of knowledge as new discoveries and unfamiliar technologies replace yesterday=s learning.@ See ACranks and Proud of it,@ *The Economist*, Jan. 20, 1996, pp. 86-87.

[44]The classic text on this is still Sidney Pollard, *The Genesis of Modern Management*. Harmondsworth: Penguin Books, 1965, pp. 213-25. See also Arthur Redford, *Labour Migration in England, 1800-1850*. Manchester: Manchester University Press. Reprint. Manchester: Manchester University Press, [1926] 1964; for a recent restatement see John S. Lyons, "Family Response to Economic Decline: Handloom Weavers in Early Nineteenth-Century Lancashire." *Research in Economic History* 1989, Vol. 12, pp. 45-91.

Some new technology was in fact deliberately designed to exclude males and favor women and children, as was the case in the early factories of the Industrial Revolution.[45]

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[45]Maxine Berg, *The Age of Manufactures, 1700-1820*, Second edition. London: Routledge, 1994, pp. 144-55. Carolyn Tuttle, "Children Hard at Work During the Industrial Revolution," unpublished manuscript, Lake Forest College, (1996), pp. 156-175.

The protection of skills and specific human capital is often combined with other forms of rent-seeking through the creation of barriers to entry and the control of output. This is clearly a widespread interpretation of the European craft-guild system which ruled urban artisans in many areas for many centuries. In pre-modern urban Europe these guilds enforced and eventually froze the technological status quo.[46] Similar phenomena, mutatis mutandis, occurred in China.[47] It is important to stress that many of those guilds were originally set up to

[46]Kellenbenz, for example, states that "guilds defended the interests of their members against outsiders, and these included the inventors who, with their new equipment and techniques, threatened to disturb their members' economic status. They were just against progress." Herman Kellenbenz, "Technology in the Age of the Scientific Revolution, 1500-1700." In Carlo Cipolla, ed., *The Fontana Economic History of Europe* 1974, Vol. 2, p. 243. Much earlier Pirenne pointed out that "the essential aim [of the craft guild] was to protect the artisan, not only from external competition, but also from the competition of his fellow-members." The consequence was "the destruction of all initiative. No one was permitted to harm others by methods which enabled him to produce more quickly and more cheaply than they. Technical progress took on the appearance of disloyalty." Henri Pirenne, *Economic and Social History of Medieval Europe*. New York: Harcourt Brace & World. 1936, pp. 185-6; for a similar description of the Italian guilds, see Carlo Cipolla, "The Economic Decline of Italy." In Brian Pullan, ed., *Crisis and Change in the Venetian Economy in the Sixteenth and Seventeenth Centuries*. London: Methuen, 1968.

[47]See Olson, *Rise and Decline*, p. 150, and Mokyr, *The Lever of Riches*, pp. 232-33.

fulfill different functions acting as clearing houses for information, organizational devices to set-up training, mutual insurance support organizations, and sincere attempts to prevent opportunism and free riding on others= reputations. Yet over time many of them degenerated into technologically conservative bodies.[48]

[48]In a recent paper, S.R. Epstein has defended the technological role of craft guilds, pointing out that they fulfilled an important role in the dissemination and intergenerational transmission of technical information. There is no contradiction between such a role and the inherently conservative role played by craft guilds. More controversial is his claim that guilds provided a cloak of secrecy which worked as a protection of the property rights for inventors. Even if such a system could be demonstrated to have existed, most authorities are in agreement that eventually much of the guild system was overtaken by technologically reactionary forces which instead of protecting innovators threatened them. See S.R. Epstein, ACraft Guilds, Apprenticeship, and Technological change in pre-modern Europe,@ mimeo., London School of Economics, 1995. An extreme example is the printers= guild, one of the most powerful and conservative guilds in Europe which steadfastly resisted any innovation and as late as 1772 legally restrained one of its members from building an improved press. Cf. Maurice Audin, "Printing" In *A History of Technology and Invention*, Vol. 3, *The Expansion of Mechanization, 1725-1860*, edited by Maurice Daumas, New York: Crown, 1979, p. 658.

In most of Europe, then, craft guilds eventually became responsible for a level of regulation that stifled competition and innovation. They did this by laying down meticulous rules about three elements of production that we might term "the three p's": prices, procedures, and participation. As guilds gained in political power, they tried as much as they could to weaken market forces as aggregators and tended increasingly to freeze technology in its tracks. The regulation of *prices* was inimical to technological progress because process innovation by definition reduces costs, and the way through which the inventor makes his profits is by underselling his competitors. Regulating prices may still have allowed some technological progress because innovators could have realized increased profits through lowering costs even if they could not undersell their competitors. To prevent this, *procedures* stipulated precisely how a product was supposed to be made and such technical codes, while originally designed to deal with legitimate concerns such as reputation for quality, eventually caused production methods to ossify altogether. Enforcing these procedures, however, was far more difficult than enforcing pre-set prices. Finally, and in the long run perhaps the most effective brake on innovation, was *participation*: by limiting and controlling the number of entrants into crafts, and by forcing them to spend many years in apprenticeship and journeymanship, guild members infused them with the conventions of the technological status quo and essentially cut off the flow of fresh ideas and the cross-fertilization between branches of knowledge that so often is the taproot of technological change.[49] A particularly pernicious custom was the rigid division of labor between craft guilds so that each guild was confined to its designed occupation, a practice that required from time royal intervention to prevent egregious abuses.[50] Exclusion of innovators by guilds did not end with the Middle Ages or even the Industrial Revolution. In 1855, the Viennese guild of cabinetmakers filed a suit against Michael Thonet, who had invented a revolutionary process for making bentwood furniture. The *Tischlermeister* claimed that the

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[49]Particularly restrictive was the custom confining the intergenerational transmission of skills to kinship. In some industries, particularly in ironmaking, skills were the traditional realm of dynasties in which technological knowledge was kept as much as possible within the family. See Chris Evans and Göran Rydén, ARecruitment, Kinship, and the Distribution of Skill: Bar Iron Production in Britain and Sweden, 1500-1860.@ Presented to a Conference on ATechnological Revolutions in Europe, 1760-1860,@ Oslo, May 31 - June 2, 1996.

[50]Thus in the 1560s, three Parisian coppersmiths invented improved *morions* (military helmets), but were prevented from producing them because the armorers held the exclusive rights to defensive weapons. In this case they were overruled by King Charles IX. Cf. Henry Heller, *Labour, Science, and Technology in France, 1500-1620*, Cambridge: Cambridge University Press, 1996, pp. 95-96.

inventor was not a registered cabinetmaker. The suit was dismissed when the court made his workshop an "Imperial privileged factory."[51] The role of the guilds can go some way in explaining the series of technological successes we usually refer to as the British Industrial Revolution and why it occurred in Britain as opposed to the European Continent, although clearly this was only one of many variables at work.[52] Resistance was not confined to manufacturing; when large department stores were introduced into Germany following the French model in the later nineteenth century, small shopkeepers banded together and were able to convince the major states in Germany to pass a special tax on large stores to protect the small merchants from the threat of modernization.[53]

Perhaps the arena in which the largest number of technological battles have been fought since the Industrial Revolution has been in free trade. Protection for domestic industries often was identical to protection for obsolete technology. While the battles against free trade and technological progress by no means coincide, their overlap is considerable, and free trade and an open economy are by far the best guarantees for an economy to use best-practice technology. This idea goes back at least as far as David Hume, who pointed out in 1742 that "nothing is more favorable to the rise of politeness and learning than a number of neighboring and independent states, connected together by commerce and policy. The emulation which naturally arises among those neighbouring states is an obvious source of improvement. But what I would chiefly insist on is the stop [i.e. constraint] which such limited territories give both to power and authority."[54] At the same time, free trade was hardly a *necessary* condition: Britain remained a protectionist country until the 1840s, and the United States followed highly protectionist policies in the last third of the nineteenth century, yet both were highly open to

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[51]Ekaterini Kyriazidou and Martin Pesendorfer, AViennese Chairs,@ unpublished manuscript, University of Chicago and Yale University, June 1996, p. 4.

[52]In pre-revolutionary France the network of craft guilds and small producers, often supported by local authorities, was adamantly opposed to all technical innovation. See Pierre Deyon and Philippe Guignet, "The Royal Manufactures and Economic and Technological Progress in France before the Industrial Revolution," *Journal of European Economic History* Vol. 9, No. 3 (Winter 1980), pp. 611-32. The Crown did its best to circumvent this conservative force by awarding privileges, pensions, and monopolies to successful innovators and inventors. Needless to say, resistance to innovation before the Industrial Revolution took many forms, not all of which depended on the guilds.

[53]E. Andrew Lohmeier, AConsumer Demand and Market Responses in the German Empire, 1879-1914,@ unpub. Ph.D. dissertation, Northwestern University, ch. 2.

[54]David Hume, "On the Rise and Progress of the Arts and Sciences (1742)." In David Hume, *Essays: Moral, Political and Literary* edited by Eugene F. Miller. Indianapolis: Liberty Fund, 1985.

innovation.[55]

[55]The strong connection between openness and economic growth was recently demonstrated by Jeffrey Sachs and Andrew Warner, AEconomic Reform and the Process of Global Integration,@ *Brookings Paper on Economic Activity*, 1995, No. 1, pp. 1-95. Oddly enough, the technological implications of the open economy are entirely neglected by Sachs and Warner in their list of links between openness and more rapid economic growth.

In the past century resistance to new production technology has come in part from labor unions. There is no compelling reason why labor unions must always resist technological change: after all, as Aencompassing organizations@ they ought also to be aware of the undeniable benefits that new technology brings to their members *qua* consumers.[56] The growth of the labor movement=s power in Britain is often held responsible for the declining technological dynamism of post-Victorian Britain. Resistance of organized labor slowed down technological progress in mining, shipbuilding and cotton weaving.[57] Such resistance was not a hundred percent effective, but Coleman and MacLeod may well be right when they judge that labor's resistance "reinforced the increasingly apathetic attitude of employers toward technological change."[58] In printing, London=s notorious Fleet Street earned a reputation of stormy industrial relations, where management=s major preoccupation was with avoiding disruptions to production, even at the expense of high unit labor costs and restrictions on technological

[56] See Alan Booth et al., AInstitutions and Economic Growth,@ *Journal of Economic History,* 1997, forthcoming.

[57] For the cotton industry, see especially William Lazonick, *Competitive Advantage on the Shop Floor.* Cambridge, MA: Harvard University Press, 1990, pp. 78-114. In shipbuilding, for example, the boilermaker union limited the ability of employers to introduce pneumatic machinery after 1900. See Edward H. Lorenz, *Economic Decline in Britain: The Shipbuilding Industry*. Oxford: The Clarendon Press, 1991, pp. 58-59.

[58] Donald Coleman and Christine MacLeod, "Attitudes to new Techniques: British Businessmen, 1800-1950," *Economic History Review,* 39 (1986), pp. 588-611, quote on p. 606.

innovation.[59] The crisis in the Bombay cotton industry in the 1920s and 1930s, when Bombay lost much of its market share to other areas is attributed to the militancy with which Bombay trade unions fought against a technical and administrative rationalization of cotton mill practices.[60] In a recent paper, Susan Wolcott documents in detail how Indian workers were able to block successfully the implementation of larger spindles in the cotton spinning industry, not only in Bombay but in Ahmedabad and Sholapur as well.[61]

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[59]Roderick Martin, ANew Technology in Fleet Street, 1975-1980@ in Bauer, ed., *Resistance to Technology,* p. 194.

[60]Morris, AGrowth of Large Scale Industry,@ pp. 622-23.

[61] Susan Wolcott, AThe Perils of Lifetime Employment Systems: Productivity Advance in the Indian and Japanese Textile Industries, 1920-1938.@ *Journal of Economic History* Vol. 54, No. 2 (June 1994), pp. 307-324.

In our own time, labor unions have been held responsible for impeding technological progress in many industries. In the European and American auto industry, for instance, they have resisted the closing of outdated plants and the introduction of the flexible work practices and reduced job classifications that have increased the efficiency of Japanese car manufacturers.[62] Needless to say, not *all* unions have taken a consistently conservative stance against new technology: in post-1945 Sweden and Germany, for example, unions were induced to join coalitions aimed at increasing productivity. These unions were large and encompassing groups, and as the Olsonian theory suggests, their membership benefitted enough from technological progress for the benefits to outweigh the costs.

e-Externalities. The non-pecuniary aspects of new technology raise particular concerns when there are Aexternal effects@ that is, when new technology affects common resources. Much of the resistance by the environmental movement to superfast railroads, nuclear power, and advanced pesticides, for instance, deals precisely with the non-income effects of technological change. Again, such non-pecuniary effects are valued differently by different individuals and thus the outcome that political aggregators determine will differ from the market outcome. In the standard case of externalities, common resources are not priced at their marginal social cost. In a static economy, arrangements will often emerge that minimize such discrepancies. New technology compounds the transaction costs with information problems. Thus, it is difficult enough to limit the use of *known* atmospheric pollutants, but far harder to enforce agreements when the damage is unknown or in dispute. Unknown effects on shared resources thus aggravate disagreement and political resistance to technological progress.

To conclude, then, there are good reasons for subgroups within an economy to try to dethrone the free market as the sole aggregator, that is, to disallow the competitive price mechanism by itself to determine which technologies will be adopted and which will not. This effort has been undeniably successful; almost everywhere some kind of non-marketing control and licensing system has been introduced that has some agency or group of experts approve new technology *before* it is brought to the market. The next issue then should be, why should the

[62]Holmes and Schmitz, AResistance to New Technology@ p. 29. See also Martin Kenney and Richard Florida, *Beyond Mass Production*, New York: Oxford University Press, 1993, p. 315.

outcome of such a decision-making process differ substantially from the outcome of the market, and what are the sources of disagreement and debate between the different groups?

Political action within an aggregator.

Given that society has determined the aggregator, that is, the Arules of the game@ by which decisions are made, do social resistance and political action still make sense? Obviously, unless $\alpha = 1$, the non-market game is only beginning. Once the arena has been chosen, interest groups and ideologically committed activists will concentrate on getting the outcome they desire. The nature of the debate will differ of course depending on the arena and the motives of the opposition and in particular there is a distinction between the adoption of known technologies by developing economies, and that of new, wholly untried, technologies by economies on the technological frontier. We may distinguish the following forms of political action.

a *Lobbying*. The pure case in which the Alosers@ discussed above lobby to get it rejected. Persuasion and political agitation do not make much sense if the distribution of gains over the population is continuous since in that case every decision maker already has made up his or her mind and nobody is strictly indifferent; in practice however there are likely to be discontinuities in the distribution, leaving a large number of Avoters@ indifferent to the implementation of T_1. These voters would be Arationally indifferent,@ that is, because they have no or a small stake in the outcome, it is hardly worth their while to master the often intricate details of new technologies. Lobbying then involves an attempt to persuade these Aindifferent voters@ to support or resist the new technology. In this context Olson's notions of the *Logic of Collective Action* are central. When the losses are concentrated, as they often are, the losers are likely to be more easy to organize and have more political clout even if the social gains outweigh the losses.

b *Strategic behavior and logrolling.* It may be sensible in some cases to pretend to object to some technologies as part of a bargaining strategy. For instance, as already noted, workers may actually stand to benefit from a new technology, but may find it in their interest to resist it in order to eventually secure a larger part of the new technology or perhaps secure increased rents elsewhere. There is historical evidence of the use of resistance to innovations as a bargaining chip even when the interests of both sides are unclear.[63] When a new and more

[63]As Martin points out in his analysis of the British newspaper debate, Ait is rarely the case that a management

efficient technology is introduced, there are rents to be dissipated; it makes sense for unions to resist the new technology unless they can be guaranteed an acceptable proportion of the rents generated.[64] Furthermore, if there is more than one negotiation going on at one time, groups may be trading-off support or resistance for technologies that they actually do not care much about in order to secure support for their position on decisions that affect them directly.

c *Correlation effects.* Often new technology is viewed and depicted as Apackaged@ in a cultural-political deal that is undesirable even if the new technology in and of itself is. This kind of ambiguity flavors much of the political argument in non-Western nations and often is coupled with a cultural suspicion of foreigners. There is a sense that Athe magical identity is development=modernisation=Westernization.@ Especially when new technology takes the form of new products, it is often regarded to be correlated with undesirable cultural and social side-

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totally united behind technological change is opposed by unions or employees totally opposed.@ Martin, ANew Technology in Fleet Street.@, p. 204. Within management and within workers there are often conflicting interests at work, and it is often as hard to predict which position each side is going to take as it is to predict the outcome.

[64]The most detailed work on the subject has been carried out by William Lazonick on the cotton industry. His conclusion is worth repeating: "Vested interests --- in particular the stake that British workers had in job control and the historic underdevelopment of British management --- stood in the way of ... promoting the diffusion of advanced production methods." See William Lazonick "Theory and History in Marxian Economics." In *The Future of Economic History*, edited by Alexander J. Field, Boston: Kluwer-Nijhoff, 1987, p. 303. Labor viewed the adoption of new machines with "acute suspicion." Rather than block the new machinery altogether, however, their resistance was often veiled in increased demands. To secure labor's acceptance, management had to make concessions that reduced the profitability of new machinery (Peter Payne, "Entrepreneurship and British Economic Decline." In *British Culture and Economic Decline*, edited by Bruce Collins and Keith Robbins, New York: St. Martin's Press, 1990, pp. 25-58).

effects. It is then rejected by some, not because of its inherent economic characteristics but because of these externalities. The history of India, for one, illustrates this well. Headrick sums up the issue as follows:

> AThe colonized [nations] were in an ambiguous position. Western technology had led to their defeat and captivity and threatened their culture and way of life. No one illustrates their ambivalent attitudes toward Western technology quite as well as Mohandas K. Ghandi, who wore handwoven garments made of homespun yarn but also used a watch, traveled by train, and kept in touch with his followers by telephone.@[65]

[65]Daniel Headrick, *The Tentacles of Progress*. New York: Oxford University Press, 1988, p. 382.

In China and in the Islamic Middle East, too, the slow speed at which economic modernization occurred was in part the result of the association of more efficient production methods with an alien culture. Political action was aimed broadly at the culture with which the new technology was associated. Yet in recent times most cultures, suspicious as they may be of foreign influence, have come to realize that they cannot afford to reject foreign technology lock stock and barrel.[66]

[66] A notable example of this eclectic attitude is the economic nationalism preached by India's Bharatiya Janata Party whose slogan is AMicrochips, not potato chips.@ *Business Week,* Oct 23, 1995, p. 50.

Such packaging of culture and technology can take other forms. Some new technologies have been argued to have especially negative effects on women, children, or members of other special social groups. When this occurs, resistance to the new technology may occur just because these groups are deemed by some to be vulnerable and thus worthy of protection even if they themselves stand to benefit from it. A prominent example of this type or argument is the work of Vanadana Shiva, whose work combines Feminism, Environmentalism, and a fierce suspicion of Western Technology.[67] In the West, too, technological progress was associated with powerful groups from which individuals felt alienated. Thus, technological resistance against, say, nuclear power, might be viewed as Aa blow to big business or big science.@ Sociological studies suggest, however, that such resistance is fairly rare.[68] Some of the historical suspicion against new technology was related to its effects favoring commercialization. Most technological change affects the proportion of total output that goes through the market. The Green Revolution, with its heavy reliance on purchased inputs (seeds, fertilizers, pesticides), has raised serious objections on the basis of the alleged disruptions and violence that market penetration caused to self-sufficient small communities thus causing the Adepeasantization of the peasantry@.[69] In principle, however, technological progress can be either market enhancing or market curtailing. Many of the household appliances developed during the twentieth century led to home production of cleaning and cooking services that previously were carried out by hired household labor. Another correlation effect is the fear the new technology will lead to rationalization and secularization, undermining the power of religion and Atraditional values.@ Finally, correlation effects may occur simply when a new technique is somehow associated with a group that is disliked. Thus the introduction of quinine was delayed into England because it had been brought to Europe by the Jesuits and was

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[67]Shiva argues that modern technology destroys nature and is thus Aassociated with violence to women who depend on nature for drawing sustenance for themselves, their families, their societies.@ The Industrial Revolution created a Adomination and mastery of men over nature [which was] also associated with new patterns of domination and mastery over women. Vandana Shiva, *Staying Alive: Women, Ecology, and Development*. London: Zed Books, 1988, pp. xvi-xvii.

[68]See Allan Mazur, AOpposition to Technological Innovation,@ *Minerva* Vol. 13, No. 1 (Spring 1975), pp. 58-81, quote on p. 62.

[69]See Vandana Shiva, *The Violence of the Green Revolution*. London: Zed books, 1991, p. 177, 190.

known as AJesuit Powder.@[70]

d *Irreversibilities and path dependence.* Another possibility occurs when a new technology is initially adopted, but subsequently some new information emerges or some change in preferences occurs that makes people change their minds. In that case the aggregator G itself remains but the outcome changes, so that $G(T_1 \ast I) > G(T_0 \ast I)$ but $G(T_1 \ast I') < G(T_0 \ast I')$, where T_1 and T_0 are the two techniques and I and I' are two information sets. The very nature of new technological information is that it is irreversible, once learned, it is difficult if not impossible for society to Aunlearn@ a new technique, no matter how socially undesirable. This kind of phenomenon might be called the *Pandora Effect*. Even if society Aregrets@ its decision to move to T_1 it may not be able to return to T_0. If this process is anticipated, even in probability, at time 0, it is possible that society may decide not to adopt T_1 Aso that we do not regret it later.@ This is especially the case with technology that can be used both for constructive and military purposes. The classic example of such a Aregret@ is the conversion of Lewis Mumford, one of the great minds of thinking about technology in the twentieth century, from the

[70]Oliver Cromwell, who suffered from a malarial fever all his life and died of it, refused steadfastly to touch what he called Aa Jesuit treatment@ and a physician named Gideon Harvey published a book and denounced quinine as a medication because it came from the Jesuits Awith whom the less a man have to do either sick or well, it=s the better.@ See M.L. Duran-Reynals, *The Fever Bark Tree: the Pageant of Quinine*. New York: Doubleday, 1946, pp. 54-56. AQuinine@ in Roderick E. McGrew, *Encyclopedia of Medical History*. London: MacMillan, 1985, p. 298.

technological enthusiast to the technological skeptic because of the ravages wrought by World War II.[71] Certain inventions that misfired badly have also led to difficult debates such as the current debates on pesticides, asbestos, and CFC=s. Undoing the effects of this new knowledge is costly and ending their use difficult to enforce.

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[71]Thomas P. Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm*. New York: Penguin Books, 1989, p. 448.

Given the path-dependent nature of technological change, it may make sense for a subset of the population to resist a new technology even if it temporarily increases welfare, if there is an expectation that this technology will eventually lead to the development of further technologies that it may deem undesirable.[72] In other words, technological change involves not just a choice between two techniques, but two different technological trajectories, such as nuclear vs. fossil fuel energy or direct vs. alternating current. This returns to the principle of correlation discussed above, but it involves an additional dynamic element. Political action is aimed to persuade the relevant decision maker that a certain technological avenue is undesirable even if some initial features appear attractive. Thus there is a sense, not entirely misplaced, that medical advances that made transplantations possible will eventually lead to markets in organs or that the ability to identify the gender of foetuses through amniotic fluid tests may eventually lead to selective abortion to achieve gender selection. ACyberphobia@ is in part based on the futuristic fear that impersonal and inhuman machines would eventually govern society, and that the differences between people and machines would eventually become hazy. *In vitro* fertilization techniques have resulted in a fear of the mechanization of the human reproductive process and fluoridation of drinking water have raised concerns about socialized medicine but also about the (perhaps more realistic) power of a state to affect unsuspecting individuals through the control of a network technology such as water supply.[73] There is a fear that new technologies that initially work well, will veer out of control and like Frankenstein eventually turn on their creators. Precisely because so many new technologies ended up being used in totally different ways than they were originally intended, there is a justified fear that by producing new knowledge, we may be unleashing, like the Sorcerer's Apprentice, something we may not control. The fundamental sense of concern is that some forms technological change lead to a slippery slope toward some vaguely perceived but unacceptable future outcome,

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[72]An example would be the campaign conducted by the *Foundation on Economic Trends*, a Washington lobby dedicated to fighting the spread of biotechnology. As of now, there is no registered case of any damage caused by biotechnology. Yet the fear persists that if these technologies took off, somehow others would emerge that would be extremely harmful.

[73]Fluoridation was first introduced in the United States in 1945, but in 1992 only 62 percent of Americans using public water enjoyed its benefits. In Western states, where the aggregator took the form of referenda rather than an imposition by elected representatives, adoption rates were generally lower (2 percent in Nevada, 16 percent in California). This reflects classical Luddite skepticism about Amass medication@ but also correlation effects such as Amistrust of big government.@ There is no evidence of any negative side-effect of fluoridation except a minor discoloration of teeth when the quantities are higher than optimal. See *Scientific American* Volume 274, No. 2 (Feb. 1996) p. 20.

which -- while never absolute -- has affected much of the underlying thinking of opponents.[74] A generalization of the Pandora Effect would be that all might agree to prefer T_1 to T_0 but if T_1 leads in high probability to T_2... T_n and T_n is less desirable than $T_{0,}$ It may well be the case that today we would be better off without knowing how to release nuclear energy, but this option no longer exists.

[74]Arnold Toynbee wrote in 1958 that Aif a vote could undo all the technological advances of the last three hundred years, many of us would cast that vote in order to safeguard the survival of the human race while we remain in our present state of social and moral backwardness.@ Cited by Noel Perrin, *Giving Up the Gun: Japan's Reversion to the Sword, 1543-1879*. Boston: David R. Godine, 1979, pp. 80-81.

f. *Diversity*. Another concern is that new technology may lead to a decline in diversity and thus block future technological change. In agriculture this is literally true: settling on an optimal breed or variety may in fact be hazardous simply because the existence of parasites suggests that negative frequency dependence might be the optimal strategy. The Irish disaster of 1845-50 was caused by overcommitment to a seemingly superior crop.[75] In general, there is a conflict between the obvious advantages of standardization in network technologies and the need for diversity. While at times diversity is hopelessly inefficient (such as in the case of watch batteries), in other cases it keeps alive technologies that later on might be the base of important breakthroughs. New technology may thus be resisted because it may reduce the array of future technological choices. This seems to be the root of the suspicion with which American computer specialists regard Microsoft and Intel.

[75] This is strongly argued by Shiva in her criticism of the Green Revolution, who maintains that high-yielding varieties in the long run will be more vulnerable to pests and diseases due to lower genetic diversity (Cf. Shiva, *Violence of the Green Revolution*, ch. 2).

g. *Uncertainty and heterogeneity*. Above all, however, there is inherent uncertainty in the adoption of genuinely new technologies, which makes any aggregator a matter of dispute. The inherent nature of new technology is that its effects cannot be anticipated with accuracy.[76] Thus *any* expected benefits and costs are to some extent unknowable, and the more radical the innovation, the deeper this ignorance. Suppose society agrees on the aggregator, but there is uncertainty as to the value of $G(T_1)$. This creates a double-barrelled problem: For one thing, individuals do not know what the value of G(T) is and thus make decisions on the basis of a subjective probability distribution F_i (T). Secondly, they weight the outcomes by a loss function $L_i(T)$. Disagreements occur both because of heterogeneity in the F_i's and heterogeneity in the L_i's. Even if individuals agree on the probability distribution of the outcomes, they could differ in their rate of risk aversion and in the shape of the loss function they associate with certain outcomes. Equally important, however, is heterogeneity in the expectations about the probability density function of $F(T_1)$. Resistance and political conflict will occur if the distribution is such that there are enough individuals who believe that $G(T_1) < G(T_0)$. Let G_0 be the point at which the new and the old technologies Abreak even@ and f(G) the number of people who believe the net benefits of the new technology to

Install Equation Editor and double-
click here to view equation.

be G. Then if:

the new technology will be Avoted@ in existence. Note how complicated the debate is: individuals might agree on the *mean* of the subjective p.d.f. and yet come to different conclusions if they disagree on the variance or even on the size of the left tail. If the probability assigned to a major disaster in a nuclear plant is estimated at 0.1% per year by some or 0.001% per year by others, the decision may well come out different even if the rest of the p.d.f.

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[76] Nathan Rosenberg, AUncertainty and Technological change,@ presented to the Federal Reserve Bank of Boston Conference on Technology and Growth, Chatham, MA, June 5-7 1996.

look remarkably similar. Precisely because of the unknown consequences of new technology, persuasion, pressure, and propaganda (that is, political action) will inevitably remain part of technological decisions.

In practice, it is difficult to disentangle heterogeneous expectations from heterogeneous preferences. There are, however, obvious exceptions: the resistance to nuclear power in the West, especially, has been shown repeatedly to be strongly correlated with perceptions of danger.[77] With respect to nuclear power and genetic engineering, society is clearly divided into optimists and pessimists, whose subjective probability density functions over the outcomes of a new technology differ. Moreover, there is a tempting if invalid tendency to draw inferences from one technological outcome to another: the thalidomide affair has imposed restrictive brakes on the development of new drugs.[78] There is also a serious spillover effect when one poorly executed project such as Chernobyl raises questions about the desirability of nuclear power altogether. Logical inferences from single events about the social costs and risks of entire new technologies are hard to make. James Jasper has noted that Athe Three Mile Island accident in 1979 and the Chernobyl accident confirmed, interestingly, both the American antinuclear drift and the French pro-nuclear program. And neither accident did much to alleviate Swedish ambivalence about the future of its nuclear program.@[79] More than anything else, however, predicting the results of new technology is hard precisely because it is *new* and there are no reasonable precedents. Genetically modified crops are resisted by environmental activists despite the complete lack of evidence that such plants are in any way more likely to be poisonous than those occurring in nature.[80] The vague sense that if something is unfamiliar, it is likely to go somewhere very wrong, seems as powerful politically as it is irrational and socially costly.

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[77] Allan Mazur, AOpposition to Technological Innovation,@ p. 66. For more recent discussions, see especially the work of Dorothy Nelkin and Michael Pollack, *The Atom Besieged*. Cambridge, MA: MIT Press, 1981 and Jasper, AThree Nuclear Controversies.@ .

[78] Joachim Radkau, ALearning from Chernobyl for the Fight against Genetics?@ in Bauer, ed., *Resistance to New Technology*, pp. 335-55.

[79] James M. Jasper, AThree Nuclear Energy Controversies,@ in Dorothy Nelkin, ed., *Controversy: Politics of Technical Decisions*. London: Sage Publications, p. 108.

[80] In April 1997, one million Austrians signed a petition for a total ban on all genetically modified foods, and a number of European countries have banned their farmers from growing genetically modified maize. *The Economist*, April 26, 1997, p. 81.

Systemic Resistance

A different reason why society might resist innovation that seems attractive on the surface has to do with cross-technique spillover effects. As we have seen, *all* evolutionary systems have some source of resistance to change or else they might collapse into the indeterminacy Kauffman describes as his Asupracritical region.@[81] Yet the technological choices offer some sources of inertia that are not found in nature. Unlike biology, industry can mold its own selection environment by the development of rules of behavior that evolve spontaneously but the purpose of which is presumably to preserve the status quo and protect existing firms. Nelson points out that such action may be central in determining what design or system becomes dominant.[82]

Technology, too, occurs in Asystems@ meaning basically that components that are changed will have effects on other parts with which they interact. This implies that a change in technique from T_0 to T_1 is likely to change costs subsequent to its adoption through unintended consequences to other components. Many of these occur through a variety of externalities or network effects: electrical equipment, trains, software, farming in open field agriculture, all shared the problem of interrelatedness. In order to work, they require a uniformity we call standardization, and thus single members cannot change a component without adhering to the standards. Yet here, too, the analogy can be pressed too far: in technology -- but not in nature -- we can invent "gateway" technologies in which the incompatibilities are overcome, including for instance electrical convertors from 115V to 220V or railroad cars with adjustable axes that traveled on different gauges. Positive feedback traps can occur in

[81]Kauffman, *At Home in the Universe*, p. 294. Kauffman conjectures that Athe enhanced diversity of goods and services can lead to a further explosion of the technological frontier...if the social planner deems them useful to the king.@

[82]Nelson, ARecent Evolutionary Theorizing,@ p. 77.

technological systems, but tend to be rare in open economies because of competitive pressures from outside. Yet they do occur: American color TV has been Astuck@ now for decades at a low quality screen (of a low definition). IBM-based computers still struggle with the often paralyzing constraint of 640 K RAM in Aconventional memory,@ the nemesis of computer games and many multi-media applications. In both cases it has turned out to be costly and tricky but not impossible to devise a Agateway@ solution.

The complementarities involved (broadcast-reception in the case of TV; software-hardware in the case of computers) are characteristics of one of the most often occurring sources of technological inertia in history: frequency dependence.[83] A new technique cannot be successful until it is already adopted by a sufficiently large number of users. Similarly, in natural selection, new species cannot propagate unless they can mate with a sufficiently similar creature. This kind of model sounds almost discouraging, since in its strictest sense it means that only success succeeds, a blueprint for total stasis. Obviously, in *some* cases this hurdle can and has been overcome, but it should alert us that in normal situations new technological ideas that might on the face of them work well do not Acatch on@ and eventually vanish without a trace. IBM's OS/2 operating system, much superior to MS/DOS, was rejected because it was not sufficiently Acompatible,@ as were DAT tape players and Beta - system VCR's.[84] A special case of frequency dependence is learning by doing, where average costs decline with cumulative output. It is not always possible to know exactly how important these learning effects would have been in products that never made it mass production. They are the outcome of an experiment never performed. Would airships have become safe and fast (in addition to being quiet and fuel-efficient) had the world of aviation not switched to fixed-wing aircraft in the interwar period? If Volkswagen and Toyota had tried to implement a steam engine in their mass-produced models, would steamcars have been perfected to the point where they could

[83]For a recent survey of this literature, see Brian Arthur, *Increasing Returns and Path Dependence in the Economy*, Ann Arbor, University of Michigan Press, 1994. See also Paul A. David, APath Dependence in Economic Processes: Implications for Policy Analysis in Dynamical System Contexts,@ CEPR working papers, April 1992.

[84]The most famous but also controversial example is the DVORAK keyboard, thought to be superior to the standard QWERTY system. See Paul A. David, "Understanding the Economics of QWERTY: the Necessity of History." In *Economic History and the Modern Economist* edited by William N. Parker, 30-49. Oxford: Basil Blackwell, 1986. S.J Liebowitz. and Stephen E. Margolis, 1990, "The Fable of the Keys." *Journal of Law and Economics* Vol. XXXIII, (1990), pp. 1-25.

have put up as good a competition to the four-stroke internal combustion engine as the Diesel engine? Could the same be said for two-stroke engines, Wankel engines, and so on?

Concluding Remarks.

One of the main re-discoveries of the new growth theory and recent thinking about economic development is the possibility of the poverty trap or multiple equilibria. Another way of thinking about the issues discussed in this paper is that it is possible for an economy to be Astuck@ at a low level of income because the institutions it has are somehow inappropriate for technological progress. Usually the literature has thought of institutions as affecting the allocation of resources or the formation of capital. As technological progress, both home-made and imported, is still regarded as one of the main engines of growth, the suitability of institutions to the successful adoption of new ideas is an important question. Simple economic models may be difficult to construct here, but by a combination of political economy with the lessons of economic history, some insights into the causes and consequences of resistance and opposition to technological change can be drawn. The deeper question is whether sustained economic growth is the exception and stagnation the default, or whether, as argued especially by E.L. Jones in his *Growth Recurring*, economic growth is a natural condition for most economies, but more often than not political and cultural impediments drag an inherently dynamic economy into stagnation and poverty. This debate may seem to some a bit like an argument whether a zebra is black with white stripes or the other way around. In either case, the political economy of technological progress must occupy its rightful place at center stage.