

The Political Economy of Technological Change:
Resistance and Innovation in Economic History

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Introduction

If technology is one of the prime movers of economic growth, how exactly are technological decisions made? A technological decision is taken whenever a new technique is proffered, and firms have to decide whether to adopt it or not. It might seem that in the vast majority of cases this decision is trivial: if the new technique increases efficiency and profits it will be adopted, otherwise it will not. But historically speaking, few economies have ever left these decisions entirely to the decentralized decision-making processes of competitive firms. There usually is, at some level, an non-market institution that has to approve, license, or provide some other imprimatur without which firms cannot change their production method. The market test by itself is not always enough. In the past, it almost never was.

Much as economists might perhaps deplore the fact, therefore, 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? Could it be 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?

New technologies have failed and opportunities have been missed despite their ostensible economic superiority. 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 inroach 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.¹

¹William 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.

Petty speaks of scepticism and doubt. When radically novel technological ideas are first proposed, a normal reaction is that it will not work because otherwise we would have thought of this ourselves. Yet throughout history technological progress has run into another, more powerful, foe: the purposeful self-interested resistance to new technology. Without an understanding of the political economy of technological change, the historical development of economic growth will remain a mystery. 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 goods; 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.² Precisely because such resistance must work outside the market and the normal economic process, artificial distinctions between the “economic sphere” and the “political sphere” for this class of problems are doomed. 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 “system” resists a novel and improved component because it does not fit the operation of the whole.

²For 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.

Technological inertia in many societies has often been ascribed to irrationality, technophobia, a blind adherence to traditional but outmoded values and customs. Yet as Timur Kuran has shown, conservatism and rationality are not always mutually exclusive³. 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.

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.⁴ 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. "Fitness" in this context does not just mean technical superiority but political power and social preferences, based on beliefs, rhetoric,

³Timur Kuran, "The Tenacious Past: Theories of Personal and Collective Conservatism", *Journal of Economic Behaviour and Organization*, Vol.10 (1988), pp. 143-71.

⁴For 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.

prejudice, marketing, propaganda, and bargaining.

In the natural world, the concept of fitness is well understood. Yet the selection of new life forms of superior fitness is the exception rather than the rule. 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.⁵ 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. Selection 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.

⁵Gregory Bateson, *Mind and Nature: a Necessary Unity*. New York: Dutton, 1979, pp. 175-76.

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. Stability in the systems of living beings is maintained by what biologists term genetic cohesion. As Mayr has recently explained, “Just 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 “congealing” 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.⁶ 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.⁷

⁶Ernst Mayr, *One Long Argument: Charles Darwin and the Genesis of Modern Evolutionary Thought*. Cambridge, MA: Harvard University Press, 1991, pp. 160-61.

⁷For 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.

In the economic history of technology, too, change occurs despite the formidable forces pitted against it. Radically new technological ideas, from antibiotics to nuclear power to telegraphy, have emerged time and again despite the systemic inertia from which the technological system seems to be suffering. The dynamic may be similar: a complex 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 “punctuated 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.⁸ Most recent research in modern evolutionary biology suggests that the dynamic of evolution, too, proceeded in intensive spurts separated by long periods of stasis rather than in linear progressions.⁹ At times, it seems, some more resistance to technological change might have reduced costly experimentation, needless multiplication of standards, and continuous model changes. An example is the frenetic rate of change in the US airplane industry in the years after World War I, in which a feverish drive for continuous progress probably slowed down the emergence of a mass-produced standard plane which would have reduced the cost of flying.¹⁰ Clearly, then, not *all* resistance to technological change is necessarily socially detrimental.

The analogy with evolutionary biology underlines the rather unlikely nature of continuous technological progress. Technology may be said to be subject to *technological cohesion*, 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 “mutagens” 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

⁸Joel 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.

⁹For an accessible summary, see Niles Eldredge, *Reinventing Darwin: The Great Evolutionary Debate*. London: Weidenfeld and Nicholson, 1995.

¹⁰C. Derek Johnson, "Markets in the Air: the Development of American Aviation Culture, 1918-1934," Unpublished draft, Northwestern University, 1997.

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."¹¹ 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 such 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 new technology itself but rather in terms of the rules that are to be followed in making these decisions, such nonlinearities become understandable.

¹¹Robert 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.

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.¹² 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.¹³ 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.¹⁴ 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

¹²See Douglass C. North, *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press, 1990, p. 87.

¹³For 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 "biological coevolution and technological coevolution ... may be governed by the same or similar fundamental laws."

¹⁴Richard R. Nelson, "Recent Evolutionary Theorizing About Economic Change," *Journal of Economic Literature*, Vol. XXXIII (March 1995), p. 64.

technological change can, in this fashion, be reinterpreted in a wider context as a defense mechanism against the possibly chaotic consequences of disruptions in the fabric of a traditional society.

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 “supracritical region.”¹⁵ Yet the technological choices offer some sources of inertia that are not found in nature. Unlike biology, production technology 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.¹⁶

Technology, too, occurs in “systems” 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, telephones, farming in open field agriculture, and all mechanical devices using interchangeable parts, all shared the problem of interrelatedness. In order to work, they require a uniformity we call standardization, and thus single members

¹⁵Kauffman, *At Home in the Universe*, p. 294. Kauffman conjectures that “the 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.”

¹⁶Nelson, “Recent Evolutionary Theorizing,” p. 77.

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 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 "stuck" now for decades at a low quality screen (of a low definition). IBM-based computers for a long time struggled with the often paralyzing constraint of 640 K RAM in "conventional 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 "gateway" 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.¹⁷ Frequency dependence occurs when 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. As noted, in *some* cases such hurdles could and have 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 "catch 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 "compatible," as were DAT tape players and Beta -system VCR's.¹⁸ 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

¹⁷For 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, "Path Dependence in Economic Processes: Implications for Policy Analysis in Dynamical System Contexts," CEPR working papers, April 1992.

¹⁸The 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.

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? Would small mass-produced “flivver” personal planes have dominated the civilian airtravel market if their production had been pursued vigorously? 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 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?

Rules and Resistance

I now turn to a brief analysis of the political economy of technological change. 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. Unless all individuals accept the “verdict” 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.¹⁹ 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.²⁰ One important distinction should be made between the introduction of a

¹⁹As one author has put it, “opposition 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, “Controlling Technology” repr. in Albert Teich, ed., *Technology and the Future*, N.Y., St. Martin’s Press, 1993, p. 217.

²⁰Martin 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.

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 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 “support” or “object 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 $\langle 0,1 \rangle$ 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. 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.

I should like to suggest that the argument about a new technique is conducted at two levels. One is an argument about the nature of the aggregators that make the decision. Should there be licensing of new techniques, how is the patent office to judge novelty, to what extent can production be codified in official rules? A second level of discourse occurs once the institutions exist. Only in a pure market aggregator is there no room for politics to enter the decision making process. 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.²¹ If the market outcome rules in favor of one group,

²¹The terminology is borrowed from Avner Greif, “Micro 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.

another might find it in its interest to circumvent the market process. If the supporters and opponent of the new technique could form separate societies the optimal outcome would be to separate them. Because they cannot and one of them has to live with the undesirable outcome, the struggle consists of the attempt of the members of each group to set up an aggregation rule (for example, the market) that is most consistent with its interests.²²

²²Joel 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.

An example would be when the majority of poor people resist an innovation attractive to wealthy consumers. In that case there will be a difference between the market, in which “votes” are weighted by purchasing power and a democratic process, where each person has one vote.²³ In decisions about technology, at least, there could be a serious inconsistency between democracy and continuous innovation.²⁴ In other words, unlike the optimism of 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.²⁵ The technological decision-making in democratic societies is clearly inefficient, but at least the experience of the twentieth century is that totalitarian societies by and large do even worse.²⁶ Insofar that technological decision-making is made in the political market, there is no reason to believe that the decisions will be in any definable sense efficient -- we are strictly in worlds of second- and third-best.

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 “yes” 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

²³It clearly is highly ironic to cite here a prominent Indian businessman, Titoo Ahluwalia as saying that “the 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.

²⁴The 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, *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.

²⁵For an interesting discussion which concludes firmly that “democracy entrenches economic freedoms, and in doing so underpins growth,” see “Why Voting is Good for You,” *The Economist*, Aug. 27 1994, pp. 15-17.

²⁶Barbara 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. “But in India,” she added, “a 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. See 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.

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 “no” 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. In his classic article “Gunfire at Sea”, Elting Morison has described the resistance put up by the navy against the introduction of continuous-aim firing in the U.S. Navy in the first decade of our century. In this case the resistance was overcome by the officer in question appealing directly to President Roosevelt over the head of his immediate superiors and the officers in charge of the Bureau of Navy Ordnance.²⁷ Market failure occurs when network- or other forms of externalities are present, and hence the resistance to technology is often most pronounced when there is already another reason to take decision-making out of the hands of private enterprise.

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. Thalidomide-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

²⁷Elting E. Morison, “Gunfire at Sea; A Case Study of Innovation.” In id., *Men, Machines, and Modern Times*. Cambridge, MA.: MIT Press, pp. 17-44.

technological change they wish to influence, not its very existence.²⁸

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 $\langle 0,1 \rangle$ is $G = aG_M + \beta G_D + (1-a-\beta)G_V$ where $a+\beta \leq 1$. The pure market outcome occurs only when $a = 1$. 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 a 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 a and β as probabilities or proportions of the “cases” that are decided in one arena or another thus lends some intuitive meaning to G .

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 a , 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

²⁸This is what sets aside the literature of “alternative” or “soft” technology advocated by Amory Lovins from the shrill and technophobe positions advocated by, say, Ivan Illich and Chellis Glendinning.

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 a, 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 $a < 1$, 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.²⁹ 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, 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 “experts” 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

²⁹The 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.

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.³⁰

³⁰Dorothy Nelkin has pointed out that the very fact that experts disagree -- more even than the substance of their disagreement -- leads to protests and demands for more public participation. See Dorothy Nelkin, "Science, 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.³¹ 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.³² 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 “is excluded in principle.” Jones realizes that a caste system, too, could never be an *absolute* constraint on economic growth, it “may constitute an infuriating brake, yet it will not be able to switch off a motor located somewhere else in society.”³³ 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.

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.³⁴ 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 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.

³¹Bernard Lewis has pointed out that in the Islamic tradition the term *Bidaa* (innovation) eventually acquired a seriously negative connotation, much like “heresy” 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.

³²Morris D. Morris, “The 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.

³³Eric L. Jones, *Growth Recurring*. Oxford: Oxford University Press, 1988, pp. 103-06.

³⁴Joel Mokyr, “Cardwell's Law and the Political Economy of Technological Progress,” *Research Policy*, Vol. 23 (1994), pp. 561-74.

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.

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 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.³⁵

³⁵An 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.

When, then, will opposition to the market as the arbiter of innovations emerge? 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.³⁶ 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.³⁷ Technology is something profoundly unnatural, as Freud observed in his *Civilization and its Discontents* when he compared it to an artificial limb. While many societies encourage the search for new inventions, one author sighs, "we remain, in part, appalled by the consequences of our ingenuity and ... try to find security through the shoring up of ancient and irrelevant conventions."³⁸ Technology is regarded by many writers as something uncontrollable and incomprehensible and thus somehow evil in itself. The literature on this issue is rather large and cannot be done justice to here.³⁹

The distinction I drew above between indigenous technologies and imported technologies was of considerable historical importance. When a technology has never been tried before and is genuinely novel, there is a serious fear of the unknown, resulting from risk aversion or deeper fears of "devils we do not know." The resistance to a new technique has two separate roots, heterogeneous preferences and heterogeneous expectations. If there is a probability that a technique may mal- or dysfunction, people with high risk aversion will resist it. Secondly, precisely because it is new and there are no exact precedents, people could disagree about the magnitude of the probability of a failure, so that even people with the same rate of risk aversion would have

³⁶In the psychological literature there is a great deal of emphasis on seemingly "irrational" phenomena such as fear of new technology. Psychological "diagnosis" of "cyberphobia", "technophobia" and even "neophobia" [fear of new things] is common. For a thoughtful debunking of this literature, see Martin Bauer, "'Technophobia': a Misleading Conception of Resistance to New Technology" in Bauer, ed., *Resistance to New Technology*, pp. 87-122.

³⁷In most of humanity's history, *all* technology, has been 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.

³⁸Elting E. Morison, "Gunfire at Sea; A Case Study of Innovation." In id., *Men, Machines, and Modern Times*. Cambridge, MA.: MIT Press, p. 43.

³⁹For a historiographical introduction, see Langdon Winner, *Autonomous Technology*. Cambridge, MA: MIT Press, 1977, pp. 107-34.

different attitudes. In societies that adopt tried technological changes from other countries such fears of the unknown are secondary, and the resistance is more likely to come simply from having observed the negative effects of a new technology elsewhere. But such “learning” effects are relatively rare.⁴⁰ More likely are what we could call “correlation effects”, that is, technology is viewed and depicted as “packaged” 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 “the 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-effects.⁴¹

Self-interest, of course, counts too. Economists have used the term “rent-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 “loss-avoidance.” Historically, most of the resistance to new technological change had economic reasons: potential losers set up

⁴⁰The most obvious example is the prohibition of fire arms in Tokugawa Japan, where the government successfully was able to eliminate the production and use of muskets in its attempt to retain a monopoly on violence.

⁴¹The acceptance of quinine in Britain was impeded by the association of the drug with the Jesuits. Oliver Cromwell who died of a malarial fever refused to take it as a “Jesuit treatment” and Gideon Harvey’s *The Family Physician and the House Apothecary* (1667) denounced it as coming from Jesuits. The full acceptance of the drug – the first truly effective chemical pharmaceutical agent -- was delayed by half a century by such resistance.

obstacles to obstruct innovation. At this stage, I will first 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. 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 to the new technique is to increase total income so that the gains of the winners exceed the losses of the losers. 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 a 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 “pure” market system, they need not enter the debate. The main question is why for some individuals technological change is income-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 “Machinery,” 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. Notwithstanding a long debate and intricate national debate about the “Machinery Question” raised by Ricardo, nineteenth century Britain did not suffer from a secular increase in structural employment feared by Ricardo and the Luddites alike.⁴² 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.⁴³ 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 “job growth and the introduction of new technology appear to be complements rather than substitutes. The Luddites were wrong.”⁴⁴ The danger here is one of overaggregation: it is likely that compensating fluctuations in labor demand in different sectors will spawn substantial resentment even if total demand for labor is unchanged. The cost of making the transition is often non-negligible, and workers are likely to observe the decline in their own sector before they perceive better opportunities elsewhere.

⁴²As Berg has noted, Ricardo did not imply that technological unemployment was inevitable. It did not occur because machines substituted for labor, but only because they reduced the stock of “circulating capital.” It would thus only occur when a country's capital stock was very small and where the construction of machinery demanded a “strong switch to fixed capital” -- hardly a description of nineteenth century Britain. See Maxine Berg, *The Machinery Question and the Making of Political Economy, 1815-1848*, Cambridge: Cambridge University Press, 1980, p. 67. Cf. John Hicks, *A Theory of Economic History*, pp. 148-54, 168-71. None of the theoretical demonstrations that in certain unlikely configurations some (temporary) unemployment can be caused by the introduction of “machinery” is tantamount to a demonstration that such technological unemployment did in fact occur on a large scale. It is telling that working class leaders, in Berg's view, resisted the machine because of its economic distress, such as “technological unemployment, long hours of alienated factory labour, and the smoking blight of rapidly expanding industrial towns” (Berg, *Machinery Question*, p. 17) -- the former clearly being contradicted by the latter two.

⁴³M.J. Campbell, “Technology and Rural Development: The Social Impact.” In M.J. Campbell, ed., *New Technology and Rural Development: The Social Impact*. London: Routledge, 1990, p. 26.

⁴⁴David G. Blanchflower and Simon M. Burgess, “New 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.

b. Capital Losses. A different problem occurs when physical capital is of a “putty-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 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.⁴⁵ 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

⁴⁵It 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, “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.

technology themselves, which is precisely what happened in Lancashire during the British Industrial Revolution. In 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.⁴⁶

⁴⁶A 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 “confined to relatively well-off fishermen who could afford to invest in extra equipment and suitable boats.” See Kristine Bruland, “Patterns 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 “perfect” 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.⁴⁷ The so-called “workshop 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.⁴⁸

⁴⁷Gregory Clark, “Factory 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, “The Growth of Large-scale Industries,” p. 675.

⁴⁸Adrian Randall, *Before the Luddites*. Cambridge: Cambridge University Press, 1991.

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.⁴⁹ Beyond that, technological change affects the regional distribution of production and employment, thus forcing 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.

⁴⁹Ken Alder, *Engineering the Revolution: Arms, Enlightenment, and the Making of Modern France*. Princeton: Princeton University Press, 1996, chs. 4-5.

d- Human Capital. The opportunities for conflict are much wider when we consider human capital.⁵⁰ Skills and experience are acquired over a lifetime, but the ability to learn new skills declines over the life cycle.⁵¹ 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.⁵² 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.⁵³

⁵⁰In 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, "Resistance to New Technology and Trade Between Areas," Working paper, Federal Reserve Bank of Minneapolis, 1995.

⁵¹As *The Economist* put it recently, "What 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 "Cranks and Proud of it," *The Economist*, Jan. 20, 1996, pp. 86-87.

⁵²The 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.

⁵³Maxine 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.⁵⁴ Similar phenomena, mutatis mutandis, occurred in China.⁵⁵ It is important to stress that many of those guilds were originally set up to

⁵⁴Kellenbenz, 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.

⁵⁵See 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.⁵⁶

⁵⁶In 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, "Craft 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 journeymanhood, 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.⁵⁷ 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.⁵⁸ 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

⁵⁷Particularly 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, "Recruitment, Kinship, and the Distribution of Skill: Bar Iron Production in Britain and Sweden, 1500-1860." Presented to a Conference on "Technological Revolutions in Europe, 1760-1860," Oslo, May 31 - June 2, 1996.

⁵⁸Thus 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."⁵⁹ 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.⁶⁰ The one industry in Britain in

⁵⁹Ekaterini Kyriazidou and Martin Pesendorfer, "Viennese Chairs," unpublished manuscript, University of Chicago and Yale University, June 1996, p. 4.

⁶⁰In 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.

which it fell behind technologically even during its era of industrial triumph in the first half of the nineteenth century was in watchmaking, where both labor and entrepreneurs were resistant to innovation.⁶¹ Resistance was not confined to manufacturing; when large department stores were introduced into Germany following the French model of retailing technology 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.⁶²

⁶¹David Landes, *Revolution in Time*, Cambridge: Harvard University Press, 1983, chs. 17-18, esp. pp. 300-01.

⁶²E. Andrew Lohmeier, "Consumer Demand and Market Responses in the German Empire, 1879-1914," unpub. Ph.D. dissertation, Northwestern University, ch. 2.

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."⁶³ 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 innovation.⁶⁴

⁶³David 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.

⁶⁴The strong connection between openness and economic growth was recently demonstrated by Jeffrey Sachs and Andrew Warner, "Economic 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 “encompassing organizations” they ought also to be aware of the undeniable benefits that new technology brings to their members *qua* consumers.⁶⁵ 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.⁶⁶ 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."⁶⁷ 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 innovation.⁶⁸ The crisis in the Bombay cotton industry in the 1920s and 1930s, when Bombay lost much of its

⁶⁵ See Alan Booth et al., “Institutions and Economic Growth,” *Journal of Economic History*, 1997, forthcoming.

⁶⁶ 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.

⁶⁷ 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.

⁶⁸ Roderick Martin, “New Technology in Fleet Street, 1975-1980” in Bauer, ed., *Resistance to Technology*, p. 194.

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.⁶⁹ 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.⁷⁰

⁶⁹Morris, "Growth of Large Scale Industry," pp. 622-23.

⁷⁰ Susan Wolcott, "The 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.⁷¹ 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 “external 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

⁷¹Holmes and Schmitz, “Resistance to New Technology” p. 29. See also Martin Kenney and Richard Florida, *Beyond Mass Production*, New York: Oxford University Press, 1993, p. 315. It is interesting to note that when the distinction between management and labor becomes fuzzy with worker participation in management, technological breakthroughs encounter less resistance. When United Airlines became employee-owned, workers devised a simple way to use electricity to power idling planes instead of jet fuel, saving the company a reported \$20 million a year. The executive in charge of the matter remarked that “in the past we would just have sent out an edict and nothing would have happened.” “United we Own,” *Business Week* March 18, 1996, pp. 96-100.

experts approve new technology *before* it is brought to the market. The next issue then should be, why should the 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?

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. Whereas the new Growth Theory has emphasized the importance of technological progress and its relation to capital formation, both human and physical. It has failed, thus far, to build a bridge to the “New Institutional Economics” in looking at the kind of institutional set-up that is most conducive to technological progress. A plausible way to do this is to understand that resistance to progress can be based entirely on rational and selfish reasons and that there are therefore causes, deeply rooted in the logic of collective action, that impose an element of inertia and stasis on the technology used by any economy. Another way of thinking about the issues discussed in this paper is that it is possible for an economy to be “stuck” 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. What I have suggested here is that 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.⁷² 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

⁷²See Joel Mokyr, "Institutions, Technological Creativity, and Economic History," *Innovazione e Materie Prime*, Vol. I, Nos. 2-3 (1993), pp. 27-42 (in Italian). Reprinted in A. Quadrio Curzio, M. Fortis and R. Zoboli, eds., *Innovation, Resources and Economic Growth*. Berlin: Springer Verlag, 1994, pp. 39-59 (in English).

around. In either case, the political economy of technological progress must occupy its rightful place at center stage.