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The Impact of Transformative Technologies on Governance: Some Lessons from History

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Table Of Contents

Introduction ... 1
Project Objectives ... 2

Comparison of Four Transforming Technologies ... 4
Printing Press ... 4
Steam Engine ... 4
Electric Motor ... 7
Atomic Energy ... 7

Some Observations about the Impact of Transformative Technologies on Governance ... 8
Some Specific Parallels from the Past ... 8
General Observations ... 9

Preliminary List of Factors Favouring Successful Governance of Transformative Technologies ... 10
Societal infrastructure factors ... 11
Direct government support and control of technology ... 13
Factors affecting the policymaking process ... 14

Concluding Observations ... 16

Suggestions for Future Work ... 17

Appendix 1 – The Printing Press ... 18
Background ... 18
Impacts and Effects ... 18
Major Actors ... 20
Policy Levers ... 20
Policy Issues, Actions Taken, and Consequences ... 20
Conclusion ... 22

Appendix 2 - The Steam Engine ... 24
Background ... 24
Larger Social and Political Context ... 25

Appendix 3 - The Electric Motor ... 27
Background: ... 27
Impact ... 28

Appendix 4: Atomic Energy ... 31
Background ... 31
Impacts and Effects. ... 31
Major Actors: ... 32
Policy Levers ... 32

Issues, Actions Taken, and Consequences 33
Conclusion 34

The Impact of Transformative Technologies on Governance - Some Lessons from History

Bill Woodley[1]

Introduction

This report summarizes the results of a project undertaken for the Institute on Governance and the Law Commission. It is part of a scoping study about the impact on governance of major technological transformations such as the incredibly rapid developments now taking place in information and communications (ICT for short), as well as the biological (life) sciences.

At the current time, countless complex changes are happening very quickly: In addition to the ICT revolution and biosciences revolution, there are quantum leaps in the development of new materials and nanotechnology, globalization, and global environmental change, to name a few, with societal impacts building on one another that are impossible to predict.

Much has been written about the economic impacts of the industrial revolution and its implications for future economic growth. The history of technology and its relationship to economic growth has also been a longstanding academic interest. More recently, scholars have started to examine the social and cultural impact of technology. But the impact of past technology on governance does not seem to have attracted much research attention. The implications for governance are striking, as Homer-Dixon suggests in his recent book, The Ingenuity Gap:

> "Many people argue that modern communication technologies will open up a new era of grassroots democracy. Personal computers, the Internet, fax machines, and cell phones aid local activities that create and strengthen community institutions. They help build social capital in the form of networks of trust and reciprocity, and this social capital makes governments more humane and responsive...
>
> "Some new information technologies unquestionably strengthen the state: security cameras scan public thoroughfares, squad cars are linked directly to databases on criminals, and law enforcement agencies can search effectively through huge numbers of fingerprint and DNA records. Ultimately, though, the balance appears to tilt in the other direction - towards a weakening, not a strengthening of the state...
>
> "Many people, especially in Western cultures that promote individualism and personal liberty, believe this shift is indisputably a good thing .... People who adopt this perspective tend to downplay, even to distrust, the state's role in providing public goods - including well functioning markets, courts, and health and educational systems - that are critical to our well-being. Their implicit assumption seems to be that ... human beings, even with astonishing technological power at their disposal, will behave constructively if left to

[1] Special thanks to Robert Nichols for his assistance with the background research for this paper.

their own devices.

But human nature and behavior can be malicious as well as benign. And so our assessment of the consequences of a technology-driven shift of power to individuals has to be much more complex."[2]

This situation suggests many questions that could be examined, such as:

- What are the major public policy choices with respect to any particular transforming technology? Should the state buy in, thus making it a public good; and if so, at what stage? Can or should the state decide not to buy in?
- Should there be a "neutral space" beyond the reach of the state for experimentation and development before public policy decisions are made about particular technologies?
- Is it possible to determine the impacts of technology on culture, and vice versa?
- Can anything be learned from past technology revolutions that might help us today?

This paper addresses the last question to provide some data that may help as a first step in answering the other questions. There is, it must be said, a presumption in this line of enquiry that technological transformations are inevitable, if not generally beneficial. These assumptions can certainly be questioned. They get a little attention in this paper (but not much); still the historical examples may help readers assess whether or not there are realistic public policy choices to be made about the pace of technological change.

Project Objectives

This project investigates several important technologies from the past that have had major impacts on society, with the aim of identifying any parallels or lessons about the types of challenges we will face in dealing with the ICT and bioscience revolutions. A related purpose is to look for hypotheses about successful governance in an age of continuing technological transformations.

Definitions

Technologies, according to Ursula Franklin, are tools that help us live and work together, but of course they can also have destructive uses. *Transformative technologies* can be broadly defined as technologies with:

1. many varied purposes
2. applications or impacts on large parts of society and the economy
3. much scope for improvement initially;
4. strong complementarities with other technologies; and
5. long term effects on values, power structures and ideas.

This definition draws heavily on the concept of a general purpose technology developed by the

[2] **Homer-Dixon**, T., **The Ingenuity Gap**, Alfred A. Knopf, 2000, pp.324-326

economists Elhanen Helpman, Richard Lipsey and others[3].

Governance is defined here as the process whereby, within accepted traditions and institutional frameworks, interests are articulated by different sectors of society, decisions are taken, and decision-makers are held to account. This definition includes the workings of established institutions of government (legislative, administrative and judicial), organized interest groups such as churches, trade unions and companies, and processes for involving other less organized interests in civil society. This paper pays particular attention to the role of government as it has developed over the years surveyed, although it does refer at times to the role of other actors in governance such as the organized Church.

Scope of Work

Four technologies - printing, steam, electricity and atomic energy - were chosen after consulting several lists of the most important inventions in the course of history, with the aim of providing some coverage of the relationship between governance and technology from the 15th to the 20th Centuries. Printing was selected as an example of an information/communications technology. Atomic energy was selected because it raises moral questions and has positive and negative, life and death implications, as do biosciences.

The work done was entirely a survey of secondary sources rather than original research. It is presented as a scoping study with some concluding observations and ideas for further work at the end. As a scoping study, it is only fair to warn the reader that the paper leads to more questions than answers.

The first phase focused on the invention of the printing press and its impact on Europe in the early modern era. Research was undertaken to find out what actions the authorities, and others, took both to encourage and to control this important technology, and how effective those actions were. Six research questions were posed:

1. What were the major impacts and effects of the technology?
2. Who were the main actors?
3. What policy levers did they use?
4. What governance actions were taken to reduce the negative and harness positive impacts and effects?
5. What were the consequences of these actions? Who benefited and who was detrimentally affected by these actions?
6. What else could have been done?

The second phase of the project extended this analysis to the steam engine, electric motor and atomic energy, with help from Robert Nichols. Using this base the paper then tries to identify some lessons learned from the past that could become “good governance characteristics” for the future, with particular reference to the current ICT and biosciences revolutions.

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[3] **Helpman, E**, editor: **General Purpose Technologies**, p.49-51.

Comparison of Four Transforming Technologies

Table 1 summarizes the answers to the 6 research questions about the impacts of each technology, and the governance issues and actions that resulted. A short sketch about each technology is provided below, and more details can be found in Appendices 1 - 4.

Printing Press

Printing technology first developed and spread in early-modern Europe during the consolidation of nation and city states, when monarchs were engaged in power struggles with feudal lords and the Catholic Church. The printing press, and the myriad of products it produced, contributed to the reformation, the rise of capitalism and democracy, and had a significant impact upon almost every major development that has shaped the modern world since 1450.[4] Governance as we know it today could not exist without the printed texts of laws that are published consistently and widely, unlike the earlier manuscripts or royal proclamations were.

Few effective levers were available to national governments, but they tried in particular to use regulation, direct funding, and publicity. European governments, the protestant church and later the Roman Church took some actions to encourage the spread of the technology when they realized it was in their interest to do so. These same institutions generally did not act effectively, or they acted too late, to control the printed word. Much effort and energy was expended unsuccessfully trying to enforce the Index of Banned Books, for example. In contrast, printing was successfully controlled in the Middle East and China.

Steam Engine

The steam engine, which was invented in the 18th Century, was a key determinant of the industrial revolution, urbanization, and the arrival of an organized industrial labour force. The first use was for pumping water out of coal mines in Britain, and by 1800 steam power had many manufacturing uses leading to a rapid expansion in goods and services. But mass production meant bringing raw materials and sending finished products over wider areas, a problem solved by the steam locomotive and steamboat. Thus the steam engine also had a major impact on worldwide transportation and communication, opening new areas for growing food, facilitating imperialism and the expansion in power of the nation state. By encouraging urbanization, the steam engine also contributed to expanding schooling, literacy, and broadening the base of the governance process.

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[4] The analysis of the impact of the printing press draws heavily on the mammoth 2 volume work by **Eisenstein,** Elizabeth L., **The Printing Press as an Agent of Change,** Cambridge University Press, 1979.

Table 1: Comparison of Transforming Technologies - Some Governance Issues Surrounding their Introduction and Diffusion

	Printing **introduced c 1450** **diffusion takes 50-100 years**	**Steam Engine** **introduced c 1765** **diffusion takes 50 —100 years**	**Electricity** **introduced 1821** **diffusion takes 75 -100 years**	**Atomic Energy** **Introduced 1945** **diffusion takes 15 years**
Major Impacts and Effects of the Technology	- wider distribution and faster spread of knowledge - shift from oral to written culture - increase in reading leads to development of vernacular languages, loosening of local ties and the rise of the nation state; - fragments Latin Christendom - facilitates the development of bureaucracy and enforcement of the rule of law. - creates need for copyright law and makes possible patent protection of inventions	- industrial revolution - creates economies of scale, new products, new production techniques and new industries - mechanizes labour and impacts industrial relations - fosters speedy, reliable transport and communication - expands nation states by making possible colonial empires	- leads to development of the assembly line - impacts factory layout, work organization and efficiency - creates centralized power grids, but also facilitates decentralization of industry - transforms domestic life - revolutionizes lighting and paves the way for many new products such as the telegraph, telephone, radio and computer - advances role of the state in supporting scientific research - first example of the state helping to develop a theoretical technology before there is a practical application for it	- changes the scope and rules of warfare and brings pressure to create international organizations - heightens doomsday thinking and global environmental consciousness - concept of changing nature - politicization of scientists - medical, economic and safety concerns
Major Actors	- States - Catholic Church - scholarly reading public - new reading public - printing industry	- States - industrialists - industrial labourers	- States - industrialists	- States - scientists - international organizations
What Policy Levers Used, and When?	Nothing done at the time the technology was introduced. Later: - legislation/Regulation - military force - direct investment - publicity (but state-level governance was relatively weak in the 15th C)	Technology introduced and largely developed by private initiative, but diffusion strongly supported by state using: - funding - guarantees - legislation/regulation.	The technology was introduced with strong state support in the form of: - funding - guarantees and - legislation/regulation. Again, much of the development done by private sector.	State leadership in the development and use of the technology. Direct state action took many forms, e.g. funding, military force, espionage, regulation, monopoly industrial activity.

Governance Actions Taken to Manage Change and Take Full Advantage of the Technology	- In Europe, states licensed private sector printers; and empowered state and religious censors (e.g. the Index). Churches and states also create their own publishing houses for books, newspapers and periodicals. - In Middle East and China, state and religious control and other factors discourage wide adoption of the technology	- large state-supported infrastructure projects (e.g. railways). First governmental attempts to plan the location of economic development. - refinements in financial services, and state guarantee of a monopoly to private sector investors - development of a labour market, as well as (belated) government regulation of safety and health effects	- large state supported hydro and fossil fuel power projects, and planning and development of national electricity grid. - state guarantee of a monopoly to private sector investors - belated government regulation of safety and health effects	- At the national level, total state control, or state regulation and licensing of all phases of production from mining to final disposal. - creation of International Atomic Energy Agency - Governments co-opt all possible sources of expertise leaving few independent centres of intellectually respectable criticism. - Predominant focus on weapons rather than peaceful uses
Action Consequences	Many individuals were incarcerated, tortured or killed. This had little impact on the spread of the technology in Europe, but some on what was printed. Persecution of printers in France and Italy may have helped move the balance of power in Europe northwards.	Some duplication of infrastructure and wasted effort in determining its ideal location, but overall State intervention led to successful exploitation of the technology	Overall State intervention led to successful exploitation of the technology	- Cold War, and feeble attempts at international regulation - bargaining process between have and have-not nations for peaceful use benefits - major long-term health and environmental consequences
What else could have been done? Consequences of Inaction?	- the failure of the Middle East and China to exploit this technology has had lasting consequences in their development of science, among other things. - Over 200 years before first copyright laws are developed and applied - possible consequences?			- public fear and perhaps apathy heightened by failure to regulate consequences effectively

The state played the major role in building the infrastructure to exploit the steam engine, particularly the financing of railways. While construction was often a private-public sector partnership, the investment and route planning required state leadership in the form of tax and land grants, and raising and guaranteeing funds, for example. Governments also somewhat reluctantly assumed responsibility for some of the social impacts of the industrial revolution.

Electric Motor

Scientists discovered electromagnetic field theory long before the first electric motor began to hum in 1821. For perhaps the first time, theory preceded application - a reversal of the traditional relationship between science and technology, but the one we consider more usual today. Up to that time, craftsmen and tradesmen were the originators of most technological advances as they altered their working methods, and only later did they refer the advances to scientists for an explanation why an improvement worked as it did. The exploitation of electricity is also one of the first examples of state (and other) support for technical research into a theory before there was a clear practical outcome in mind.

Over the next 75 years, the chief use of the technology was for electric lighting, but gradually the telegraph, telephone, radio and a myriad of electric machines and gadgets appeared that revolutionized domestic life as well as work. Initially the new technology was not competitive with steam, but it had a number of advantages, especially when adapted to move long distances over a network of wires that distributed electric power widely and made it instantly available. Government support was needed to build this network around the turn of the 20th Century, to overcome the cost disadvantage associated with the short peak period for electric lighting. Once the power grid was in place, the transformation began. For example, the layout and location of factories was decentralized. No longer was it necessary for machines in a factory to be clustered around a central drive shaft powered by steam or water - they could be laid out according to the work flow, each with its own electric motor. Nor was it necessary for the factories themselves to be clustered around the source of power - they could be located close to markets, raw materials or other scarce resources. Access to cheap power was a ticket to the creation of wealth, so the location of generating facilities and the infrastructure to distribute power made winners and losers of individuals, cities, whole regions and countries. This was a major governance issue with electricity as it had been with the railways.

Atomic Energy

The theoretical work leading up to the splitting of the atom was done by European physicists in the first years of the 20th Century, and the practical applications of these scientific discoveries proceeded in step with the march of fascism across Europe. The political context ensured that governments would play a major role, resulting in the first controlled chain reaction in 1942 and the devastating bombs dropped on Hiroshima and Nagasaki in 1945. By the 1960s nuclear power stations were being developed, and many medical, agricultural and industrial uses were discovered for various isotopes.

Atomic energy has dramatically changed the rules and scope of warfare, and relations among nations. It has heightened “doomsday” thinking about the possibility of destroying all life on earth, and both military testing and civilian accidents like Three Mile Island and Chernobyl have stimulated global environmental consciousness. Another result has been the politicization of scientists, beginning in the 1930s with their concern about the potential of a bomb, rising with some feelings of betrayal over the way it was used in 1945, and leading to the founding of the Bulletin of the Atomic Scientists with its doomsday clock. Because of the great scarcity of nuclear physicists, their skills have been greatly sought after by governments, and most have been pressed into government service at one time or another in developing or regulating nuclear weapons or nuclear power. This close relationship may have muted the open scientific criticism of government decisions and actions. The scale of investment required to harness nuclear technology may also have limited the amount of independent thought and action in this field. In any case, there was never any open discussion about the public policy choice to opt for nuclear power.

Despite the precautions taken to protect the military secrets of nuclear fission at the end of WWII, the spread of this deadly and powerful technology could not be controlled internationally, and the separation of military and peaceful uses has blurred. Moreover, problems in regulating the uses and abuses of atomic energy seem to have contributed to public fear, perhaps a feeling of helplessness, and cynicism about governments.

Some Observations about the Impact of Transformative Technologies on Governance

Some Specific Parallels from the Past

Of the four technologies, printing has the most relevance to ICT in the present day. The current information revolution speeds up or expands many of the trends begun by the arrival of the printed word - such as cheaper, faster dissemination of information, better cataloguing and cross-referencing, faster feedback. Some parallels from 500 years ago are:

- The environment in which print prospered was one where there were no effective national borders and no international governance beyond the Roman Church. Globalization has created the same conditions for the spread of information today, as governments are unable to prevent information from crossing borders. Nevertheless, eastern societies made a concerted effort to control the spread of printing, the same way some countries like Saudi Arabia, Iran and China have tried to restrict the Internet.

- The way that printing advanced knowledge is relevant today. First, there was a rush to print every ancient Latin text that publishers could find, including those filled with superstition and errors. This caused an early drift toward degraded information, but provided a broad comparative base from which scholars quickly advanced. And some disciplines such as botany and geography took advantage of the wide distribution that printing made possible to collect new information from a much larger group of observers, and this led to progress far beyond what had been possible prior to the invention of printing. Surely this same process is now happening with the Internet.

- On the other hand, some characteristics of current IT hark back to pre-print culture. For example, it used to be difficult to recognize the official versions of manuscript documents, and the same problem arises reading documents on the Internet. One of the main advantages of print over manuscript was what McLuhan and others called "typographical fixity". We've lost it! And will we come to rely more on the spoken word rather than written word, as they did in the manuscript era? Modern authors raise a concern about IT "crowding out" face to face communication, but I have not found not evidence this worried anyone at the time of the print revolution.

- Printing **probably** helped weaken local community ties, and certainly helped forge new links with larger communities. In the 15th and 16th centuries, the new links had enormous political, economic, religious and scientific consequences, and they have continued. The Internet has the potential to create similar impacts, both negative and positive. But did printing actually weaken local ties, and if so, can we prevent this happening again? From a governance standpoint, one current challenge is to harness the potential of the Internet to create or "thicken" durable community ties, and improve citizen feedback.

Turning to the current biosciences revolution, the development of atomic energy offers some comparisons. There are the obvious dangers on the one hand of life and death powers in private hands. But on the other there is the cautionary tale of the mistakes that are made with a closed policymaking process, when governments control all reputable scientific expertise[5].

General Observations

Although it is dangerous to draw conclusions from such a small sample, three general observations can be made about these 4 transforming technologies.

First, the facilitating role of the State in exploiting technology has increased through the years. Governments played virtually no supportive role in the spread of printing technology, but quite a bit in the diffusion of steam (by funding railways), and even more with electricity through urban and rural electrification. With electricity there is a hint that government-supported research created the conditions for exploiting the invention in the first place, and that is definitely the case with atomic energy. And not only were government funds essential for developing nuclear power; for national security reasons no government could afford to have this technology in private sector hands. The active, interventionist role of the modern state is not too surprising. Nationalism barely existed when printing was invented in the 15th Century, and the institution of the nation state has increased in power in part because of the changes wrought by these technologies. This observation raises a whole host of other questions about the appropriate extent, timing and form of government support: just what sort of research, and what is appropriate infrastructure? Getting these answers right is not easy.

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[5] Among other sources this section draws on **G. Bruce Doern, Government Intervention in the Canadian Nuclear Industry**, Canadian Institute for Research in Public Policy, Montreal 1980; and **J. E. Hodgetts, Administering the Atom for Peace**, Atherton Press, New York, 1964.

In summary, it seems clear that an important function of the state has been to support wide public access to technology - electricity in particular would not likely have had as wide and as fast a transforming impact without it. One can speculate that printing would have had an even more powerful impact if states had supported the teaching of literacy[6], and there is undoubtedly a role for governments in overcoming the digital divide today.

The second observation is less clear-cut, but still worth exploring. While national governance mechanisms can support the adoption of technology, they seem less able to control or prevent its spread. Regulation of these pervasive technologies probably becomes more difficult the more widespread they become. There were examples of persistent regulatory failures in all four technologies, whether it was the church or state trying unsuccessfully to prevent the printing of certain types of books, or control the health and safety impacts of steam and electricity, or prevent the spread of lethal radioactive materials. There are exceptions. Although control measures were not very successful in Europe and the West, the history of printing in the Middle East and China suggests that strong action by church and state helped delay adoption of that technology for centuries. But as discussed in Appendix 4 this is not solely due to regulation. In the case of atomic energy, regulation has been partially successful, at least at the national level. Not until the 20th Century have there been any attempts at international regulation of technology, and they too have met with very mixed results to date.

Third, as could be expected from our definition of transformative technologies, these four caused long-term shifts in the power structures of society. For example, 15th Century nobles at court suffered a loss of status if they could not read, and the virtual monopoly of the church and universities over learning was broken as literacy spread (a precursor to the current digital divide). Guilds lost power and many workers lost their jobs to mechanization in the eras of steam and electricity, and there was a shift from rural to urban life. Atomic energy is somewhat different, although it has increased the tension between have and have-not nations, and perhaps between scientists and the rest of society.

One of the hypotheses proposed at the beginning of this project was that those in power would resist new technologies, the thinking being that they stood to lose as new wealth, opportunities and new power structures threatened the status quo. But in the century following the introduction of each of the first three technologies, existing power structures seemed to cope fairly well. This includes the Catholic Church which, after a slow start, began in the mid-16th Century to use printing to its advantage. Of course if one takes a longer view, these technologies caused massive social and economic dislocation. But power elites – who are important actors in the governance process - were certainly not always forces of conservatism and reaction.

Preliminary List of Factors Favouring Successful Governance of Transformative Technologies

It is necessary to state at this point that the experience to date strongly suggests that transformative

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[6] As noted earlier, there is scant evidence about the expansion of education and literacy in the early modern era, but one source indicated there were fewer students attending schools in France in 1650 than in 1450!

technologies are unruly, unpredictable forces that cannot be understood or controlled . At best, governments and other actors can try to nurture positive forces and establish certain conditions that will encourage flexibility and fast response to negative forces. With this in mind, there are perhaps three types of factors that could be considered important in getting the best (and containing the worst) from transformative technologies. These are a) societal infrastructure factors, b) direct government support and control of technology; and c) factors affecting the policymaking process itself.

Societal infrastructure factors

These are basic conditions that would invigorate not just technology but also the creative energies of society as a whole. They could be either directly or indirectly supported by government, but they are generally associated with a passive, non-interventionist state role[7]. The assumption in this section is that government helps create the conditions for expansion of technology, but does not take direct action to constrain it or deal with its negative social/cultural etc impacts. The state helps set the rules of the game but has low visibility as a referee. There are many possible success factors in this section, and they are frequently interrelated. Here are four important ones (not an exhaustive list):

1. **Intellectual freedom** to question, experiment and publish. Secrecy discourages the dissemination of knowledge and the development of connections between inventions and new applications for them. Bad theories continue unchallenged and unsuccessful policy responses are likely to be repeated in a climate of secrecy. Ensuring free traffic in ideas is a function of governance as well as a necessary (but not a sufficient) condition for successful governance. Having good antennae is the only way to ensure major problems get on the government's policy agenda in time. This condition may have been partially met in China and the Middle East (in that inventions travelled freely across borders), but there was no institutional support for those who generated the ideas.

2. **Patent/copyright protection** for the originators of ideas. This would appear to be a corollary of intellectual freedom, because without some incentive or benefit inventors would not be willing to publish their ideas (but note: not available at the introduction of the printing press; not useful at the development of nuclear fission). It is a function of government to provide this protection, as well as to ensure that the information is available to the public and not locked up in private files.

3. **Effective information management systems**. One of the first impacts of the printing press was

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[7] Others have addressed the issue of success factors, in particular how to encourage innovation. The OECD in 1971 came up with a list of objectives for government policy that would help create a climate favourable to technological innovation. These were:

- Industrial competition
- Regulation of social costs/benefits
- Procurement policies
- Science-based entrepreneurship
- Equitable rewards
- Labour and regional adjustment policies
- Mobility of scientists in/out of government
- Trade liberalization

the development of better information management systems than had existed in the manuscript era. Readers were able to locate and compare information in books more easily than in manuscripts when the publishing trade developed edition and page numbers, tables of contents, indexes, compilations and catalogues. These innovations greatly facilitated the finding and transmission of consistent information, and they are credited among other things with having a decisive impact on the Dutch war of independence from Spain and the development of the scientific revolution in the 17th Century.[8] What was true in the 17th Century is probably also true for the diffusion of any transformative technologies. Innovation quite often results from chance encounters, random connections, stray ideas, and experiments that go totally off course. This suggests the need to provide a marketplace for ideas, perhaps managed like the financial marketplace. There may be a regulatory role for government here.

One current author, Homer Dixon, has noted that: "as new communications technologies swamp us with information, we often devote more time to managing information and less to producing new, high quality ideas".[9] There could be some doubt about this conclusion given that computers also help us organize and sort information more efficiently than in the past. Nevertheless, information overload is a valid concern that has to be addressed.

4. **The corporate form** provides space for discussion and resolution of disputes without threatening the state. This is important both to incubate ideas and to ensure potentially adversarial points of view can be brought to the government's attention if they are not already on the policy radar screen. "Corporate" does not necessarily mean private enterprise, as it was the universities that provided this essential space in Europe in the Middle Ages, a space that did not exist in China or the Middle East. Printing and papermaking were invented in China and in the 8th Century they were passed from Samarkand to Baghdad: why did they not transform those societies they way they did Europe 700 years later? One reason appears to be the lack of independent institutions of higher education and other "zones of officially sanctioned neutral space" [10]where established theological, medical and scientific beliefs could be challenged, without interference from the state. This impeded the development of science and technology in China and the Middle East up to the 20th Century.

   One way or another, it is essential that there be credible sources of scientific expertise outside government. One of the problems in the development of atomic energy is that almost all the experts were co-opted by governments, leaving few if any independent sources of credible scientific criticism outside[11].

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[8] Dudley, L *The Word and the Sword: How Techniques of Information and Violence Have Shaped Our World*, Cambridge University Press 1991, Chapter 4.

[9] Homer-Dixon, T. *The Ingenuity Gap*, Alfred A Knopf, 2000, p.26

[10] Huff, T, *The Rise of Early Modern Science: Islam, China and the West*, Cambridge University Press 1993. p.316. See also p.361 "The epitome of the learned man was one who had mastered the Confucian classics and who, through long and arduous study, understood the place of man in a harmonious cosmos. It was he who could advise the emperor on statecraft and moral affairs and, being thus enlightened, could follow a course that would avert natural catastrophes and social unrest.......This does not mean that there was no room for the techniques of the exact sciences, for practical men of industry, or for the pursuit of science but that these ideals were subordinate to the classical forms of being."

[11] In Canada, perhaps as a result, only one approach to nuclear power was officially supported, and it has not

This factor and factor #2 above are closely related to the rule of law, which might be added to this list as a basic societal success factor in its own right.

Direct government support and control of technology

As part of the process of balancing winners and losers, governments often try to speed up or slow down technology by acting in each of the four areas above. For example,

- intellectual freedom could include policy evaluations and studies funded with public money. On the other hand, governments sometimes censor or withhold research findings, or support natural monopoly suppliers of technology (like hydro);
- protecting benefits for inventors could extend beyond patents and copyrights to include tax breaks and development funds. But governments can also make exceptions to patents as many do now with respect to AIDS drugs, and they place restrictions on technologies by regulating their health and safety effects;
- information management systems could include policies to help companies obtain information about, and adapt, technologies already known and used elsewhere;
- governments can fund pressure groups, citizen participation programs, and other private sector sources of research and possible dissent.
- Governments can impose ethical reviews or other forms of disclosures for scientists which may engage the public at different levels, e.g. lay overview panels.

What are the success factors involved in this balancing process? The active interventionist role of the state is highly controversial. Some would dispute the state has any role at all to play in "picking winners" in such a complex and risky policy area as technology. The chances of success are slim, and the consequences of failure could be severe, particularly when two or more transformative technologies are interacting as at the present time. Some would even disagree with governments getting involved in early research, the way they did with the development of electricity and atomic energy, or providing infrastructure for the diffusion of steam and electricity. Others believe state support is essential, or inevitable. Few would deny the government some regulatory role, or some actions to protect losers or soften the impact of new technology. The issues in this complicated area go far beyond the research in this paper.

Richard Lipsey addressed the issue of government support for research and development in his 1996 paper. He notes that: "Every government policy, including those related to education, competition, and income redistribution will have some influence on the amount, location and direction of technological change." For Lipsey, government R&D support is a fact of life - sometimes notably successful; sometimes a dismal failure. Rather than debating the issue of whether governments should be involved, he is more interested in identifying what types of measures will be successful[12].

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been a notable financial success.

[12] Lipsey**,** R. *Economic Growth, Technological Change and Canadian Economic Policy***,** a paper prepared for the C.D. Howe Institute, 1996. He lists 4 factors that are important at the macro level:

At the micro level, he sees knowledge-based companies and individuals as the new sources of competitive advantage. But the information economy is footloose compared to the older one based on natural resources. This limits the policy independence of any individual government, as people and firms tend to move if someone else offers them a better deal. Overall Lipsey seems optimistic about highly targeted government assistance, especially if the private sector is closely involved in the selection of targets.

The notion of targeted regulation and assistance depends on policymakers having good information to help them select policy instruments, and good systems to monitor impacts and help make changes to policy. Rather than proposing specific success factors for government action, therefore, it is to these factors that we turn next.

Factors affecting the policymaking process

The original project proposal speculated about how the process for making public policy with respect to transformative technologies might differ from a more "normal" policy-making process (dealing with a single event such as discovery of a new vaccine). Seven stages of the policy process were identified, and the main complications caused by a transformative technology were identified at each stage. These hypotheses are listed in Table 2.

Some obvious questions that arise from Table 2 are: who should be involved in the policy process (i.e. governance); and when? One paramount concern is how to get an issue concerning a transforming technology into the policy process in time, or at the appropriate moment. In some cases a transformative technology might not be recognized as such, and be treated as a normal policy problem in the early stages. If policymakers underestimate the effects of a transforming technology, they could exacerbate the problems, especially the possibility of counterproductive piecemeal government actions.

Two factors seem to be particularly important, and these are added now to the list of four success factors begun earlier:

5. **A methodology to face serious hypothetical risks**, uncertainties and a variety of "legitimate" perspectives (i.e. stakeholders). This suggests the need to develop a policy process that involves a wider, fairer balancing of views than the current one.

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1. Understand and accept change - support a socioeconomic system that encourages continual experimentation and change and that restricts the power of vested interests to slow or even stop change;
2. Keep regulation flexible - so as not to inhibit the invention of new technologies;
3. Encourage created assets - governments have a responsibility to train citizens in literacy and numeracy, and to continue to support them once trained so they do not leave;
4. Be aware of the importance of foreign direct investment.

These helped in developing the 4 societal success factors in this paper.

Table 2

Stage	"Normal" Policy Process	TT Policy Process
1.Advent	clear trigger: event, invention or development	- perhaps no clear trigger for action, or need could blossom unexpectedly - widespread public interest, activity - some attempts to predict/control introduction and effects. - Perhaps pressure on national governments to act quickly to gain international advantage
2. Initial analysis	orderly analysis of options, potential consequences and costs	- some potential consequences identified but most cannot be foreseen and some not even noticed for a long time; - costs hard to determine - more likelihood of counterproductive or perverse initial policy responses and more serious consequences from these
3. Expert consultation	- reference to advisory bodies as necessary - meetings of interested parties to resolve differences of opinion	- intense discussions among the knowledgeable; - much jockeying for position among nations, companies and individuals - resistance from the status quo who often stand to lose power - urgency may inhibit learning lessons from other jurisdictions.
4. Publication of policy intention	draft government proposal to act (or not)	Piecemeal government proposals nibble at consequences; need for international action identified but no agreement to act; significant power shifts begin to take place;
5. Public consultation	- broad discussion among all major interest groups. - eventually a majority agreement achieved	- broad but unfocussed public discussion - because of magnitude of effects, more difficult to achieve a policy consensus
6. Implementation of policy decision	government action (or not)	precipitous or partial government actions = High risk of unintended consequences. The knowledgeable gain; the general public loses.
7. Feedback	response and experience lead to review after a period of time - back to initial analysis step 2.	measurement impossible because so much else is going on. Various interest groups harden their positions. Back to step 1.

Gone are the days (if they ever existed) when rational scientific testimony alone could help governments decide what to do. Given the complexity of today's issues and the number of experts with competing views, science has lost whatever charisma it had in the development of policy. The dialectical, empirical approach to problem solving is regarded as an essential precondition of the scientific revolution in the West, one that distinguished it from China and the Middle East. We now need something even better. The concept of extended peer communities is one possibility. There has to be some way to make democracy more than a "spectator sport" , as Roszak[13] calls it, where the general public sits in the stands watching experts (especially scientists) contend on the public policy battlefield. One way to empower citizens would be to improve the teaching of basic statistical principles such as the law of large numbers and sampling error, and the importance of the assumptions behind forecasts[14].

There is a need for an ethical base, and a way to translate it into practical guidelines.

6. **Trust among the actors in policymaking**, especially among scientists, the public, bureaucrats and politicians. This follows from point 5. It is becoming more important today as governments deal with more complex issues that "combine extreme uncertainty with the possibility of extended and irreversible harm"[15]. As noted above, scientists do not have all the answers and neither does any other interest group, but all can contribute some essential information to good policy decision making. Trust is the key element, and without it any methodology bringing together the legitimate stakeholders will not work. One factor that will help to create trust is agreement on an ethical base.

Concluding Observations

The sorts of changes that are called transformative technologies in this paper have far-reaching consequences on our economic, social, cultural and political lives. Past experience suggests they are far too large and complex to be predicted or controlled by governments. Yet governments have always been called upon to play some role, and it is inconceivable that the state could stand on the sidelines when there are so many positive and negative impacts, so many winners and losers vying for attention.

Although there are some clear parallels between past and present technologies, each one has been distinct in its impact. This complicates the development of an appropriate model for deciding if, when and how the state should intervene. In western societies the development of the corporate form has created a neutral ground on which some of the issues can be worked out.

There are some changes that clearly would help: a better public participation process, and a better informed citizenry, for example. Building links between the general public and scientific communities is also important, and building a base of ethics that would facilitate self regulation. It would be helpful to have more discussion of the issues, the lessons to be learned, and how these and other changes might be accomplished.

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[13] Theodore Roszak, *Where the Wasteland Ends: Politics and Transcendence in Post-Industrial Society*, page 239, quoted by Prewitt, in the article cited below.

[14] Kenneth Prewitt, article "Scientific Illiteracy and Democratic Theory", in *Daedalus*, 1983 112(2) , pages 58- 63. Prewitt also suggests citizens need to understand that all technologies impose social costs as well as benefits, and that their second order effects are both inevitable and unpredictable. These are useful suggestions.

[15] DeMarchi and Ravetz, Risk Management and Governance; *Futures* Sept 1999 Vol 31 #7, pages 743-757.

Suggestions for Future Work

The success factors need to be refined, expanded, and tested further. There are lessons to be learned from past technologies, particularly ones like the printing press that can be closely related to current technology challenges. But more may be learned from the recent past, particularly as science issues that affect government are gaining more research attention than they got 10 years ago. It would be particularly useful to find a technology issue that compares with the biosciences revolution. One possibility is the birth control pill, which has the advantage of being a widespread international technology issue with strong moral overtones. Another possibility is to move away from transformative technologies and examine government action dealing with some other international bioscience issue such as the world AIDS epidemic. This has the advantage of being an issue with a great deal of urgency, bringing pressure on governments to act quickly (always a risky situation). Finally, another idea might be to tackle the ICT revolution directly. We are at least 15 years into this, and a lot has been written about it. It would be useful to survey the literature about government experience in dealing with both support/encouragement and regulation/control. All these paths would lead to a better list of success factors.

If we look beyond the original terms of reference, there is one related line of enquiry that has already attracted a lot of research attention. It is the connection between risk management and governance, which is being actively investigated by the European Community's Institute for Prospective Technological Studies. Others are also working on this topic. How governments handle "unknown unknowns" (to borrow a phrase from Homer-Dixon) is surely at the heart of dealing with transformative technologies that are too big to be controlled. It would make sense to survey the literature in this field and perhaps contact some of them directly before doing too much more original work.

Appendix 1 – The Printing Press

Background

Printing originated in China and Japan between the 7^{th} - 11^{th} Centuries, and apparently played an early role in governance in that printing was used for administrative purposes by rulers, e.g. printed money. A book was published using moveable type in Korea in 1409. The print revolution in Europe is commonly dated from Gutenberg's combination of moveable type and a metal press, first used around 1450. Typography (for printing text) and engraving (for images) soon became common, and book and letterpress production spread very rapidly in Europe in the late 15^{th} Century. By 1500, there were about 50 presses in Germany and 120 in Italy.

It is interesting to note that printing (and papermaking before it) were invented by the Chinese and that both inventions quickly spread to the Middle East. Eventually papermaking spread to the West via Spain in the 12^{th} Century - but not printing. And neither invention was exploited in China or the Middle East to disseminate information widely and cheaply, and to advance the free flow of ideas, the way they were in the West. This is true both prior to 1450 and for a long time after as well. Many hypotheses have been advanced as to why: such as ruthless suppression by rulers, the complexity of eastern languages[16], and the rigid control of religion. There is some further discussion on these questions in the conclusion of this section.

Print Culture differed in many ways from Manuscript Culture. For example:
- wider dissemination, increased output and altered intake (i.e. new products like primers, ABC books, catechisms, calendars, guidebooks and manuals)
- standardization. Necessity and power of the printer to decide on styles (gothic and roman became standards), layout, binding, title pages.
- more and better indexing, cataloguing and cross referencing
- "Typographical fixity" and wide dissemination led to better preservation of data.
- a culture of improvement rather than degradation of texts (despite initial degradation). An increase in the output of old texts contributed to the formulation of new theories.

In general, compared to manuscripts, printed books were cheaper, more consistent, produced faster, and the information was more easily used, carried or posted.

Impacts and Effects

The printing press, and the myriad of products it produced, contributed to the reformation, the rise of capitalism and democracy, and had a significant impact upon almost every major development that has shaped the modern world since 1450. The extent of influence cannot be accurately determined and is sometimes overstated. The farther out one looks, the greater the likelihood that other factors besides printing deserve the lion's share of credit or blame. Thus our main focus is on

[16] One certain factor is the complexity of eastern languages, including the lack of a system of alphabetization, inconsistent punctuation, and haphazard pagination

impacts in the first 200 years.

Much of what follows looks less at printing's impact on the expansion of literacy than its impact on groups that were already literate. The connection between printing and literacy is complicated, and there are no reliable statistics on literacy rates before the 18^{th} Century. Probably many rural areas remained untouched by print until the coming of the railway age, although the information rural folk received had been affected by print.

Some of the most important impacts in the years to 1650 are mentioned below.

social

- printing caused a transition from a hearing to a reading public which had social and psychological impacts. Literacy loosened local ties, and improved links to larger collective units.
- printing contributed to the permanent fragmentation of Latin Christendom. Protestant divines and enlightened philosophers "both viewed printing as a providential device which ended forever a priestly monopoly of learning, overcame ignorance and superstition, pushed back the forces of evil commanded by Italian popes, and, in general, brought Western Civilization out of the dark ages.";
- wider dissemination and standardization expanded and improved feedback to authors, produced cross-cultural interchange and later instilled ferment;
- development of specialized products helped strengthen the family and encouraged the development of feminist and youth cultures [highly speculative conclusion].

economic,

- the rise of an important new industry and force for change - competition to publish old texts, produce better editions, obtain rights to new work;
- better maps and atlases facilitated the age of discovery and imperialism;
- rise of protestant centres on the borders of France and Rome, taking advantage of the Index and other restrictions on certain types of books. No single international authority could deal with the protestant printers (like Rome could)
- "Before trying to account for an "idea" of progress we might look more closely at the duplicating process that made possible not only a sequence of improved editions but also a continuous accumulation of fixed records".

institutional

- facilitated the rise of the nation state;
- helped fix the linguistic map of Europe;
- encouraged the international spread of ideas

governance

- "…the art of printing will so spread knowledge, that the common people, knowing their own rights and liberties will not be governed by way of oppression and so, little by little, all kingdoms will be like to…[Macaria = utopia]"
- more visible, consistent, organized laws improved chances of enforcement
- monarchs make laws, but typographical fixity preserves precedents and makes it difficult even

for monarchs to change them - new impetus to legal profession

Major Actors

- rulers, and those who opposed them (pamphleteers, etc)
- the catholic church and those who opposed it.
- the scholarly reading and writing public (universities, monasteries, professionals, merchants).
- the new reading and writing public (more professionals, merchants, protestant families encouraged to read bibles)
- the great mass of the "hearing public" who probably did not know how to read.
- the new printing industry itself, as churchmen, scholars and scientists became printers. Major publishing houses became centres of learning and ferment as important as universities. Also led to the establishment of the "Fourth Estate".

The use of the print medium varied greatly within each group of actors: For example, some scholars like Galileo and Vesalius were excellent publicists who used print to advance their ideas; others like Copernicus and Newton were not, but even Copernicus depended on print to assemble historical data for his new theory of the Universe.

Print broke down the walls of libraries and saved learned men a lot of time copying and book-hunting (less need for scholars to travel). In general, few if any appear to have opposed the technology, but many tried to control or restrict it to their own advantage.

Policy Levers

Printing technology first developed and spread in early-modern Europe during the consolidation of nation and city states, when monarchs were engaged in power struggles with feudal lords and the Catholic Church. Few effective levers were available to national governments, but they tried in particular to use regulation, direct funding, and publicity - in fact the policy instrument of publicity was really invented in the print era . Church and feudal lords used the same methods.

Policy Issues, Actions Taken, and Consequences

Issue 1: control and spread of the technology - protection of printing trade secrets

- governments did little or nothing to control the spread of printing technology, although some cities and some individual printers tried to protect trade secrets. Printers vied with one another to improve the technology, for example by developing better reference aids like a table of contents and index.

- self help ("how to") books disseminated knowledge more widely, eventually generating more interest in proprietary information. On a more general note, printing led to better documentation and dissemination of all types of inventions which in turn hastened the need for patent laws)

Issue 2: control and spread of information (printing generated need for copyright laws)

- the idea of intellectual property ran counter to the prevalent medieval idea of common or community property. As a result, copyright law developed slowly and unevenly - first in England e.g. Milton in 1667 gets a promise from publisher of Paradise Lost to pay more before reprinting; and Statute of 1710 grants copyright to author, not publisher. Not confirmed in France until 1794 Declaration of Rights of Man.

- From 13th Century in France and probably elsewhere shortly thereafter, rulers and local governments licensed book publishers to control what was published, and granted monopoly rights to publishing houses to print authorized editions of certain books (which were also a source of revenue). For example, Philip II of Spain joined forces with an Antwerp printer to supply all Spanish priests with some 15,000 copies of a 16th C breviary (slightly altered from the version authorized by Rome) thus demonstrating control over the clergy and evading payments to the Roman printer who had won a lucrative monopoly.

- With Maximillian's support, the Jesuits in Bavaria set up a foundation to distribute catholic books widely at no cost (e.g. Imitation of Christ by Thomas a Kempis)

- Colbert started the first scientific journal in 1665.

Issue 3: freedom of the press: what information is or should be in the public domain?

- National/State governments attempted increasingly to control the printed word for political and sometimes for religious reasons. Surveillance of printers and booksellers was the means used to try to control the spread of ideas. In 1660 there were 10 state censors in France, and in 1789 there were 160. Many authors were accused and tried for heresy or for inciting treason.

- Beginning around 1543 the Catholic church published the Index of forbidden writings (which had perverse effects), and launched the inquisition against authors of "heretical" writings. Church courts tried their own cases of heresy. The Roman church also launched its official catholic "Propaganda" printing office in 1622.

Issue 4: power of the press becomes a major factor in governance - development of the Fourth Estate.

- Governments used print to gain support for their policies, wars, etc. Louis XIII started the first royally sponsored newspaper.

- Used by monarchs in the development of a national identity and in the battle against Rome. "Translation of the Bible into the vernacular languages lent them a new dignity and frequently became the starting point for the development of national languages and literatures. The literature was made accessible to the people at the very time that the invention of printing made the production of books easier and cheaper."

- translation made technical and scholarly material more available to students as well as the common man, e.g. medical and legal texts – in 1645 English law was still in Latin.

Conclusion

In summary, European governments, the protestant church and later the Roman Church took some actions to encourage the spread of the technology when they realized it was in their interest to do so.

These same institutions generally did not act effectively, or they acted too late, to control the printed word. Much effort and energy was expended unsuccessfully in the attempt. But European governments were not strong (in some cases they did not exist), and borders were shifting and uncertain, so that within Europe it seems the free flow of ideas increased at the same time as printing did. The early modern era in Europe was a time of such ferment that it is impossible to determine whether print technology made this flood of information inevitable or whether political, social, or economic factors sealed the fate of attempts at regulation.

The situation was quite different in China and the Middle East, where governments and organized religion ruled with a much firmer hand. For example, when printed books began to arrive in Persia from Europe after 1450, they were banned and the bans ruthlessly enforced. Enforcement appears to have been effective. Printing did not catch on in the Middle East until protestant missionaries moved a press from Malta to Beirut in 1834, and the first newspaper was not started until 1889.

Printing was suppressed or officially discouraged in the east in earlier times as well. But it also seems to have fallen on barren ground in that the fundamental societal conditions were not favourable. Published information posed a serious threat to established religion, and the written word was less important than the spoken word. In both places, moreover, social institutions did not develop that could support freedom of expression, such as independent universities or other institutes of higher learning. Compare this situation to Europe in the high middle ages, where universities, towns, guilds and other organizations emerged as autonomous entities with legal rights of their own. These organizations were very important in encouraging the rapid spread of printing to many different centres in Europe.

China failed to develop independent institutions of higher education and other ”zones of officially sanctioned neutral space” [17]where established theological, medical and scientific beliefs could be challenged, without interference from the state. This impeded the development of science in China up to the 20th Century, and would certainly have limited the use of the printing press to transmit knowledge. In addition, It has also been suggested that Chinese philosophy and religion downplayed the importance of technology except in the service of the state. From the earliest times, peasants fatalistically accepted the need for the State to create irrigation works and other essential

[17] Huff, ibid, p.316. See also p.361 “The epitome of the learned man was one who had mastered the Confucian classics and who, through long and arduous study, understood the place of man in a harmonious cosmos. It was he who could advise the emperor on statecraft and moral affairs and, being thus enlightened, could follow a course that would avert natural catastrophes and social unrest.......This does not mean that there was no room for the techniques of the exact sciences, for practical men of industry, or for the pursuit of science but that these ideals were subordinate to the classical forms of being.”

infrastructure, and the state bureaucracy became very powerful. Printing was used for administrative purposes - for example, printing money - but not to disseminate information widely to the population. The role of the individual was subordinated to such an extent that all independent thought, discourse and action was discouraged except that which was officially sanctioned. This predisposed individuals to accept the power and authority of the state and had a stultifying influence on civil society in general.[18]

In the Middle East, by contrast, books were more widely available, but they were under religious control. By the 12th Century there were libraries much larger than those in Europe, filled with manuscripts, and many mosques had a public library attached. But printing was strictly controlled for fear it would threaten the single correct interpretation of the Koran, and God's name would be defiled. In science and technology, too, the situation in the Middle East was much different than in China. Islamic scholars had a very strong tradition of scientific accomplishment up to the 12th Century, at which time they were world leaders in mathematics, astronomy and optics. But there was no innovative spirit that dared to break out of the religious conception of the world's natural order, and this leadership was lost. In Arab culture there was also a tendency to distrust the written word and rely on oral testimony, including the citation of sources, from a morally reliable person. This is illustrated in the development of the education system. Each teacher had a personal authorization to teach a particular document or subject. Beyond the religious texts there was no control over alternative interpretations even though they might totally lack empirical grounding, no concept of peer review, and no strong communities of learning. In studying a subject, therefore, more information was not necessarily better, as there was no mechanism for selecting the best and rejecting the worst. As in China, the Middle East did not spawn any independent universities such as developed about the 12th Century in Europe.

[18] Other possible factors were the extreme weakness of the middle class and capitalism, absence of a church fighting for its rights against the state, or competing religions trying to defend freedom of conscience, lack of university centres of academic freedom, lack of a free press. See De Bary, William: *Self and Society in Ming Thought*.

Appendix 2 - The Steam Engine

Background

The earliest steam engines were the scientific novelties of Hero of Alexandria in the 1st century AD, such as the aeolipile, but not until the 17th century were attempts made to harness steam for practical purposes. In the 1600's the engineers working for Cosimo de'Medici II failed in their attempt to build a suction-pump capable of lifting water from a depth of 50 ft. The problem was eventually referred to Galileo, and through him, to his pupil Torricelli. Torricelli's eventual success in developing such a pump had little impact on the reign of Cosimo de'Medici II, or the people of Florence. What it did do, however, was plant the idea in the heads of European inventors that gases and atmospheric pressure could be used to build simple suctions pumps and pistons. Though the original inventions often failed and rarely achieved the desired power levels, they did indicate that if a way could be found to repeatedly create a vacuum, then atmospheric pressure itself could be used as a very power source of power. This was beginning of the steam engine.

By 1698 Thomas Savery had patented a hand-operated pump to raise water from mines by suction produced by condensing steam. Another Englishman, Thomas Newcomen, took this work and, in 1712, developed a more efficient steam engine, which was in turn greatly improved by James Watt in 1765 by adding a separate condenser to avoid heating and cooling the cylinder with each stroke. Watt then developed a new engine that rotated a shaft instead of providing the simple up-and-down motion of the pump, and he added many other improvements to produce a practical power plant. Nicholas-Joseph Cugnot, who, as early as 1769, developed a cumbersome steam carriage for roads, applied this to a transportation device for the first time. Richard Trevithick was the first to use a steam carriage on a railway; in 1803 he built a steam locomotive that in February 1804 made a successful run on a horsecar route in Wales. The adaptation of the steam engine to railways became a commercial success with the Rocket of English engineer George Stephenson in 1829. The first practical steamboat was the tug Charlotte Dundas, built by William Symington and tried in the Forth and Clyde Canal, Scotland, in 1802. American Robert Fulton then applied the steam engine to a passenger boat built in 1807. By the turn of the 20th century, the steam-powered engine was already giving way to the internal-combustion engine.

Date of Invention: 1765 (James Watt's steam engine)

Timeline of Implementation: From its early development in the late 1600's (1695), it took until about 1850's before steam engine were a major success in the west and were widely used.

Impact on (a) Corporate and Managerial Structure and (b Industrial and Labour Organization

The steam engine allowed for mechanized labour at a scale previously unseen. The steam engine's initial impact on industrialization and mechanized labour came through its use for pumping water from coal and ore mines. This mechanical labour had a two-fold impact. First, it replaced human workers and shifted the traditional working roles in the mining industry. For the first time you had routinized, mechanical labour replacing human labour. The steam engine signaled the beginnings of heavy industry and a changing role for human labour organization. Second, because of this mechanized labour, the steam engine vastly improved the industrial capacity of the nations that relied heavily on coal and ore mining, Great Britain most notably. T.K. Derry and T. Williams write:"In 1700, two years before Savery's 'Miner's Friend' was first advertised for sale, some 3 million tons of coal was mined in Britain annually. By 1800 output had risen to about 10 million tons, but by 1850 it was 60 million tons, the increase being mainly due to the demands of steam engines.

Thus, we can see that steam engines were driving to some degree both the demand and the supply end of the coal-mining sector that revolutionized British labour and industry in the early 1800's. This new mechanized labour allowed for power and wealth unseen before. The scale on which people measured industrial production was so completely unprepared for the impact that mechanical labour would have, it required a major shift in thinking. No longer were economists and politicians looking at production solely in relation to domestic demands; industrial capitalism had reached capacity levels that allowed for large-scale international trade. Its importance to not only the certain specific industries, but also to the larger social context as a whole, is reflected in the words of French scientist Sadi Carnot who, in 1824, said, "To rob Britain of her steam-engines would be to rob her of her coal and iron, to deprive her of her sources of wealth, to ruin her prosperity, to annihilate that colossal power." The solid foundations of the nation-state itself rested on its mechanized power, the steam engine.

Larger Social and Political Context

The steam engine altered its larger social and political context via the transportation industry. The huge increases in industrial production created by the use of the steam engine as mechanized labour would have been stalled and wasted without adequate means of connecting the nation. Here the steam engine played a major role as well. T.K. Dunney and T. William write, "Mankind's first great step in the conquest of distance since the development of the sail required a prime-mover that would be self-contained, reliable, and powerful— in a world, the steam-engine." This 'great step' in transportation impacted social relations and governance by permitting the extension of the state in entirely new ways.

The application of the steam engine to transportation literally carried the apparatus of the state to regions previously considered impenetrable. In state building projects, from the Canadian prairies to sub-Saharan Africa, the steam engine played an integral role. A fast, relatively reliable method to transport large numbers of troops and government agents was, whether by steamboat or locomotive, invaluable. This was particularly ambitious in the case of North America, the Canadian west in particular, where the steam engine was hailed as a nation builder, the thing that would connect a new nation 'from sea to sea'. One can imagine the thinking of Canadian leadership during the period of expansion out west. How does one build a European-style nation out of nothing? How can a state presence be implanted where one has never really existed in the form envisioned? How can one simultaneously remove the nomadic civilization of the Native peoples and replace it with something more permanent and rooted in western institutions? The answer was the implementation of state structures on the local level: bring out postal services, the police and army—all those state apparatuses which first required a line to connect them all—the railway. All this required state intervention to see through to completion due to the massive expense and effort required to create the infrastructure. The steam locomotive, for example, is a technology that required, by definition, a major investment in infrastructure. The major changes it brought to transportation and the state-locality relationship as a result, could not have been brought about without the laying of those connecting lines and initial support for the infrastructure development. This was, in the end, a partnership between the state and private sector investors, but it required the initial investment and leadership of the central state power in order for it to eventually be realized. The very nature of the technology (that is, its reliance on a major infrastructure system) implied a certain relationship between the state and the population who would benefit from the technology. State control was vitally important because of the nature of the technology. Other major examples where steam-powered transportation has played a similar role can be seen in the steamboat and the colonization of sub-Saharan Africa, and railways in India. Steam power revolutionized transportation forever and changed the capacity and role of the state.

Appendix 3 - The Electric Motor

Background:

The history of the human study of electricity may be considered to go as far back as 585 B.C., when Thales is reported by Aristotle to have said, “The stone has a soul since it moves iron.” Nearly twenty-six hundred years ago electricity was being explored through its partner field of study, magnetism. Humankind’ s understanding of electricity remained largely focussed on the magnetic properties of certain substances such as iron ore and amber for more than two thousand years. In the 1500’s the royal physician to Queen Elizabeth, William Gilbert, made a breakthrough. He was able to recognize and predict the movements of early compasses. Based on this Gilbert began theoretical work on the nature of a “sphere of vertue” and “rays of magnetic force”: the beginnings of electro-magnetic theory. From this new theoretical foundation, the understanding and development of electrical technology sprang. The first machine to generate an electric spark was built in 1663 by Otto von Guericke, a German physicist and engineer. Stephan Gray, a British chemist, is credited with discovering that electricity can flow in 1729 and in 1745 a cheap and convenient source of electric sparks was invented by Dutch physicist and mathematician Pieter van Musschenbroek. Later called the Leyden jar, van Musschenbroek’s device was the first technology that could store large amounts of electric charge. The Leyden jar revolutionized the study of electrostatics. Soon "electricians" were earning their living all over Europe demonstrating electricity with Leyden jars. In 1752, in a famous moment in American history, Benjamin Franklin proved that lightning was an example of electrical conduction by flying a silk kite during a thunderstorm. Finally, Faraday and Barnard’s electric motor had successfully applied this knowledge as early as 1821, less than three hundred years after Gilbert’s discovery of magnetic “rays”.

Date of Invention: The first electric motor was used on September 3, 1821

Timeline of Implementation: It was not until the early 20th century that electric lighting, electric motors and electrical based communication devices (telephone, telegraph) were in relatively widespread use in the west. It is difficult to say exactly when its impact was widely felt due to the breadth and variety of applications and because different parts of the ‘electrical revolution’ caught on at different times. For example, the electric motor was invented in the early 1800’s and it spurred on growth in areas like electric lighting and power-generation. The vast infrastructure that accompanies electrical power was thus developed in the late 1880’s and 90’s, but it was mainly to support the demand for electric lighting earlier on. As historians T.K. Derry and T. Williams write:

> “In retrospect it seems surprising that the use of electric-power, which held such great possibilities for electrochemistry as well as for factory purposes and traction, should have developed so slowly up to 1900 in all spheres except that of illumination. The electrical industry was important nowhere except in Germany—where Siemens & Halske had given it a flying start—Britain, and the United States; in the last-named country it employed in 1899 only 42,000 wage-earners, a number that was to rise by 1929 to nearly 330,000. The reason appears to lie largely in a double difficulty. On one hand, electricity did not easily come into use industrially except in new branches of technology, because in its early stages of development it could not compete on a cost basis with established steam-power as a prime mover. On the other

> hand, the use of electricity for lighting was characterized by a short peak-period both in the day and in the year: average demand was often no more than 10 per cent of capacity, which meant that large-scale production was too costly in overhead expenses to be readily undertaken."

Thus we can see that the general timeline for the expansion of technology powered by electricity is from the early 1800's to the mid 1900's.

Impact

a) Corporate and Managerial Structure: The literature indicates that the electric motor had a significant impact on managerial organization or decision making within corporations.

b) Industrial and Labour Organization: The overhauling of industrial organization and methods of production is directly linked to the ability to transmit electrical power over long distances with little energy loss due to friction. This is reflected in the words of economist Richard Lipsey: " The dynamo replaced mechanical power with flows of electrons, which had multiple uses. It is probably the most pervasive energy-delivery innovation of all time… The exploitation of the full potential of electricity required substantial alterations in the entire facilitating structure. One of the most important was a drastic change in the layout of factories. With waterpower and steam, the power source drove a central drive shaft whose power was distributed throughout the factory via a set of pulleys and belts. Because of heavy friction loss in the belt transmission, machines that used the most power were placed closest to the drive shaft, and factories were built with two stories to get more machines close to the shaft. At first, electricity merely replaced steam or water as the power source for the central drive shaft; the structure- countershafts, belts, pulleys, clutches, machine layout, and so on- remained adapted to the old power source. Later, the practice of attaching a separate motor on each machine (the drive unit) was adopted (after an intermediate stage of group drives). It then occurred to people that the factory be built as a single-story and the machines arranged in the order of the flow of production."

Understanding the impact of the electric motor means understanding these changes in industrial organization that took place in the late 19th and early 20th century.

c) Larger Social and Political Context: Three major impacts can be identified. First, the electric motor meant that the power source no longer needed to be in close physical proximity to the unit of application, whether it be a motor, a light bulb or a telephone. This not only meant that the interior of factories could be rearranged, as the example above illustrates, but also that the factories themselves need not be close to their sources of power. The electric motor demonstrated that work could be done by a machine that was powered from something miles away. The direct result of this was the springing up of the power station system. Factories with electrically driven machinery required reliable sources of power. The result was a network of electrical power stations being built throughout the industrial world, particularly in Great Britain and the United States. Power generation and distribution became a central preoccupation of leading industrialists in all sectors by the late 1880's. This decade is particularly important as it relates to the expansion of both the generation and distribution side of electrical power. In 1886, for example, the first great hydro-electric installation was commenced at Niagara which provided power to the Niagara Falls Power Company. This would become the model for electrical power stations worldwide within a few years. In terms of distribution, T.K. Derry writes, "the 1880's saw the beginning of general recognition of the economic advantages of central power-stations generating electricity at high-voltages and serving large areas: acceptance of this principle brought with it new problems of distribution, both practical and economic." It was during this decade that the great projects of power distribution really took hold. Initially most urban areas were mapped in a confusing criss-cross pattern of overhead electrical wires. This, however, did not remain in vogue for long. Underground cables quickly became the norm by the late 19th century as authorities in larger urban areas would not allow the more dangerous overhead versions. This spawned a vast assortment of innovations in materials for both the conduction and insulation of electricity. Plastics, ceramics, rubber and metals were all experimented with for years in hopes of producing the best materials for the job. This vast infrastructure system was not merely of significance to those labourers working directly with the electric motor; it has far reaching impacts on the social and physical landscape of the western industrialized world.

Secondly, the harnessing of electrical power had a major impact on the way people thought about power and nature. With water and steam, nature had already been demonstrably shown to contain power that could be harnessed for productive uses. However, it still remained in a relatively raw form. Water was still water and steam was merely water heated up. Furthermore, one had to build the machine around the source of power. Electricity represented a total shift from this kind of power. It was raw energy, nothing more. It took no form but energy itself and was useful in almost any machine. Energy could be transformed and transported. Dr. J. Bronowski writes:

> "The Industrial Revolution, the English revolution, turned out to be the great discovery of power. Sources of energy were sought in nature: wind, sun, water, steam, coal. And a question suddenly became concrete: Why are they all one? What relation exists between them? That had never been asked before. Until then science had been entirely concerned with exploring nature as she is. But now the modern conception of transforming nature in order to obtain power from her, and of changing one form of power to another, had come up to the leading edge of science… Energy had become the central concept in science; and the main concern in science was the unity of nature, of which energy is the core."

Embedded in the very heart of this question came electricity, the scientific discovery with the technological applications that would forever change our understanding of power and its central unity. Electricity was the central embodiment of the theories that Bronowski speaks of above.

The third major way in which the discovery of electricity and the subsequent technological applications impacted the western world was by highlighting a new relationship between science and technology—a relationship in which the state played a major role. Traditionally, craftsmen and tradesmen were the source of technological advancement, altering the methods or tools used for their particular craft. Once the technology had been developed it was the role of science, aided by the political authorities (either the church or the nation-state), would seek to understand and developed one standard explanation as to why the technology worked as it did. The theory followed the application. D.S.L Cardwell reinforces this point when he writes:

> "If we agree that thermodynamics was a gift from the power technologies to science and philosophy, the contemporaneous development of electromagnetic field theory was to prove no

less important a gift, but in the opposite direction."

For perhaps the first time, philosophers and scientists developed a theory (the electro-magnetic theory in this case) long before specific applications were found for the knowledge. This fundamentally changed the role of the political elite. Science was no longer so much concerned with establishing one consistent explanation for why technology worked the way it did. Rather, the state (and in some cases still the church) became very active in supporting scientific research for its own sake. The applications of this science, this new understanding of energy, would eventually, it was hoped, give the nation itself a competitive advantage over its enemies. This was later played out with other technologies such as steam and nuclear energy, for example.

Appendix 4: Atomic Energy

Background

The theoretical work leading up to the splitting of the atom was done by European physicists such as Ernest Rutherford, Neils Bohr, James Chadwick, Enrico Fermi, Max Planck, Ludwig Boltzmann and Leo Szilard in the first years of the 20th Century. The practical applications of these scientific discoveries proceeded in step with the march of fascism across Europe, and the political context ensured that governments would play a major role. Szilard assigned the patent for the idea of a chain reaction to the British Admiralty in 1934, so that it was not published until after the Second World War. Einstein's famous letter to Roosevelt on 2 August 1939 indicates that both Germany and the United States realized the strategic importance of uranium by that time. His letter also sets the stage for the US government to take direct action in developing atomic energy, resulting in the first controlled chain reaction in 1942 and the devastating bombs dropped on Hiroshima and Nagasaki in 1945.

The effects on governments, scientists and the general public were cataclysmic, and the event ensured that fear, but also secrecy, would forever surround this important technology. Secrecy in the development of atomic energy did not stop with the end of the war, as military research into nuclear-powered ships and other weapons expanded in many countries. These circumstances also probably delayed the development of peaceful uses of atomic energy. But by the 1960s nuclear power stations were being developed, and many medical, agricultural and industrial uses were discovered for various isotopes. For example, isotopes are used for non-destructive testing, control of insect pests, and stream flow and ground water analyses.

Impacts and Effects.

Atomic (or nuclear) energy is not usually considered by economists to be a general purpose technology because it has not yet transformed economic life. Although it has many economic uses, nuclear power does not appear headed towards replacing fossil fuel or other forms of power generation. Nevertheless at least 4 major transformative effects can be identified beyond the economic sphere. These are:

1. The rules and scope of warfare have changed dramatically since the cold war began and the major powers raced to develop more powerful weapons and defence systems. New applicants still seek to join the club of countries possessing nuclear weapons, and the threat of nuclear terrorism grows. At first the major powers developed isolated test sites in the hope that knowledge about tests, and their environmental impacts could be controlled, but this turned out not to be the case.

2. International pressure developed to monitor and control the spread of weapons, eventually resulting in limited agreement to ban most atmospheric testing. The International Atomic Energy Agency was also created to monitor safeguards in place over peaceful uses in developed countries, and to provide the benefits to nations in the Third World that did not possess nuclear

technology.

3. The advent of atomic energy heightened "doomsday" thinking about the possibility of destroying all life on earth, and both military testing and civilian accidents like Three Mile Island and Chernobyl have stimulated global environmental consciousness. This is not to negate the technology entirely, as there have been many benefits to human health, food production and industry. But medical, safety and economic concerns have not typically been addressed openly or adequately by governments, and this has spurred the development of pressure groups in civil society to act as public watchdogs.

4. Another result has been the politicization of scientists, beginning in the 1930s with their concern about the potential of a bomb, rising with their feeling of betrayal over the way it was used in 1945, and leading to the founding of the Bulletin of the Atomic Scientists with its doomsday clock. Because of the great scarcity of nuclear physicists, their skills have been greatly sought after by governments, and most have been pressed into government service at one time or another in developing or regulating nuclear weapons or nuclear power. This close relationship may have muted the open scientific criticism of government decisions and actions. The scale of investment required to harness nuclear technology may also have limited the amount of independent thought and action in this field.

Major Actors:

- national governments, beginning with US-British-Canadian weapons co-operation on the Manhattan Project during WWII. Small breeder reactors were quickly developed after the war in France, Italy, Soviet Union, Japan. Weapons technology has spread to at least a dozen countries, and the technology for power plants and other peaceful uses is widely used.
- international organizations (e.g. International Atomic Energy Agency, Euratom, Uranium Cartel)
- scientists
- both public and state-owned corporations (e.g. GE and Westinghouse in the US; AECL in Canada; Framatome in France)
- civil society organizations such as Greenpeace

Policy Levers

As noted, national governments have taken the lead in encouraging and controlling the initial development and most subsequent uses of atomic energy. These policy interventions have attempted to manage both the positive and negative effects of the technology. In the 1930s, the main lever was support of university research, followed during the war by direct action. Since then, governments have intervened at all stages of the production cycle from mining uranium ore to disposing of nuclear waste, an issue no-one has yet dealt with permanently. Governments have used many different policy instruments such as legislation (or the threat of it), direct funding of government departments, setting up state-owned corporations, grants & contributions, tax breaks, contracting, regulation, publicity, military force, espionage. The policymaking process was primarily a "closed" one of insiders, with little if any public input until the "ban the bomb" movements of the 1960s and 1970s. A continuing stream of accidents, incidents and leaked information about radiation hazards has since forced greater public disclosure about the testing of weapons and the storage and use of nuclear materials. As a result, in the past 30 years the policy process in some countries has opened up somewhat.

Issues, Actions Taken, and Consequences

National and international attempts have not been notably successful in managing the consequences of unleashing the atom. If anything, promotional actions have been more successful than regulatory or control actions.

Development and control of military uses: weapons development, leading to the Cold War, attempts at international control, the limited non-proliferation treaty of 1970, and later test bans.

Development of peaceful uses: The allied "Atoms for Peace" program after 1945 led to wide interest in controlled nuclear reactions that could produce power, medical, agricultural and industrial benefits. The most important of these was the development of expensive light and heavy water reactors for power purposes - either by national governments or with their strong financial support. The enormous costs and risks of nuclear power development were recognized from the outset. As a result, only the US gave the private sector any great share of the developmental responsibility, and investigated several alternative technologies. All other countries took the policy decision to work on only one technology and to limit the role of the private sector. But as far as can be determined, the decision to focus on nuclear power as opposed to other energy sources was not explicitly recognized as a major public policy question on which electorates should be consulted, although more recently several countries such as Austria and Sweden put the issue to a vote and decided to pull out of the field.

Regulation: Along with the development of peaceful uses came the creation of national regulatory agencies to control the production, sale, use and disposal of fissionable materials both for national security and safety purposes. As was customary in the mid-20th Century, governments relied heavily on industry to regulate itself, and the secrecy in the nuclear industry associated with national security further reduced the amount of information available to the public and even to workers in the industries concerned. There were few outside inspections of mines, hospitals, even military production facilities to see whether agreed standards and guidelines for radiation were being observed, and in many cases they were not. The consequences of regulatory failure were serious - for example, many uranium miners died in Ontario.[19]

International efforts were made both to promote and control the peaceful uses of atomic energy. In 1957 the international community agreed to create the International Atomic Energy Agency to establish and monitor safeguards over peaceful uses of fissionable material, and provide technical assistance. The major nuclear powers provided assistance to "have not" nations as long as they signed agreements (subject to international inspection) that they would not divert any nuclear

[19] see the proceedings of the Ham Commission cited in Doern: In this case, there are two parts to the regulatory failure: the standards were too weak to begin with, and they were not enforced. A contributing cause was the "insider" process for setting and monitoring dosage guidelines.

material to military purposes. The international climate was such that this Agency (and Euratom and other international organizations) was responsible only for matters nations voluntarily submitted for control. For whatever reasons, international efforts have not been successful in controlling the sale and use of plutonium for clandestine purposes. There have been problems in India, Iraq, and countries of the former Soviet Union to name a few.

As noted above, strong governmental control of civil and military exploitation of atomic energy led to a virtual state monopoly of expertise in the technology. Almost all available scientists were pressed into national service. There was some attempt at scientific independence with the founding in 1945 of the Bulletin of the Atomic Scientists. Despite these actions, the nuclear issue marks the first of many failures of science to provide magic bullets and answers that can help governments make decisions, and the start of the decline of trust and public esteem of scientists in the policymaking process.

Conclusion

Despite the precautions taken to protect the military secrets of nuclear fission at the end of WWII, the spread of this deadly and powerful technology could not be controlled internationally, and the separation of military and peaceful uses has blurred. The danger of nuclear blackmail by terrorists or rogue states is high. There have also been serious regulatory failures at the national level, although these seem to be decreasing.

Moreover, problems in regulating the uses and abuses of atomic energy seem to have contributed both to public fear, perhaps a feeling of helplessness, and cynicism about governments. Some problems such as long term disposal and international terrorism are admittedly beyond the capacity of governments to solve. But there is a pattern of governments minimizing regulatory problems that are within their control, like reactor leaks, and this has contributed to public cynicism. Better government information programs would have helped somewhat, as well as more skillful and diligent regulation.