people
in the machine

An exploration of technology and society

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Introduction

Science and technology are funny things. They are all around us, forming the content and rhythm of our lives, yet we pay scant attention to how they operate in society. This is true at a number of levels. Scientists and engineers, whom we would expect to be expert on these matters, actually devote little time to studying the *role* of science and engineering in society, their focus being more highly restricted to practice. Being a physicist or a mechanical engineer does not necessarily qualify a person to speak about how physics or mechanical engineering operate within a social context. And then there are the many individuals who are endowed with the power to make long-range decisions about science and technology, such as government leaders or business managers, but who are equally in the dark about the subject. In many cases, depending on the culture or business environment, we find that decision makers are not even technically trained, that they are making both technical and social decisions based on the opinions of subordinates who themselves are often pigeon-holed into technical and non-technical categories. Finally, there is the general public. Regardless of training, we are to differing degrees asked to make technological decisions, but do so with only experience to guide us.

In a world so defined by technology, it is our responsibility to approach technological change with the kind of rigor and insight that we would for any other similar aspect of life. We devote great energy to analyzing political developments – they are the topic of daily conversation and usually consume the better part of a newspaper’s front page. What of technology? How should we approach it? How do we understand it in a way that advances our ability to make good technological decisions? How do we establish a culture of healthy debate about technology? To these questions this book is a starting point. It is written with all students in mind. It is meant to encourage students to analyze technology from different perspectives, to ask questions, and to form their own opinions. It is meant to engender a respect for the dilemmas of technological development and long-term economic and ecological survival. It asserts that good science and engineering are not the result of elite technocracies, but of enfranchised communities, understanding technology and making decisions that ensure the continued growth of culture and nature.

Part One

Definition

1 Compass Points

As a conceptual starting point in this book, we need to discuss the terms science and technology, as well as define their relationship to society. For the most part, this book is concerned with technology, in which science is understood to play a significant role. Modern science and technology are so intertwined that invoking one of the terms is usually sufficient to indicate the presence of the other. However, as we shall see, this is not always the case. Historically, science and technology came from two different communities with very different traditions. In the last two hundred years, the two traditions have grown close together. Modern scientists and engineers still maintain professional distinctions, but in many ways their practices have become quite similar.

The Quandary of Definitions

Is science the same thing as technology? Obviously not. Science, as compared to technology, usually refers to a systematic body of knowledge about the observable world. Technology usually refers to material goods, methods, or knowledge used to carry out human ends. Immediately you should see that this business of defining things is a tricky affair. If we start to use scientific knowledge to carry out human goals (like feeding people), then does that science become technology? And what if we pick up a rock, something natural and normally not considered within the domain of technology, and throw it at someone? Does it also become a technology (more specifically, a weapon)? What about art? Art is certainly technological in that it makes use of the material world (paint, clay, musical instruments), yet we do not normally consider art part of technology.

When most people think of technology, they usually imagine some kind of thing, a physical artifact. Yet technology may also include non-material methods and knowledge about how to do things. This suggests a distinction between the two based on knowing why and knowing how. Science is concerned with knowing why, and technology is concerned with knowing how to do something. In stressing knowledge we gain greater flexibility in our definition. We may consider practices that surround material goods as technologies (such as the ability to drive a car) as well as methods of organization, which aid in the fulfillment of human goals. As in the previous paragraph, we may find our definition becoming unwieldy. We might begin to consider organizations, such as businesses, as technologies (whether or not they deal directly with material technologies). We might also consider political structures to be technological (are these not organizations used to achieve human goals?). And what of religion? Where should our definition end?

Another way to limit our definition of technology is to see it as that which concerns the making or using of things, as opposed to the other human activities which are primarily doing (Mitcham, 153-4). Politics and religion are human doings, a computer software program is a human making.

Table 1.1
Different Ways of Defining Science & Technology

	A	B	C	D	E
Science	Systematic body of knowledge about the world	Knowing why		Contextualist (What do the actors believe?)	Historical (What is the activity's lineage?)
Technology	Material goods, methods, & knowledge used to achieve human goals	Knowing how to do something	Human making or using of things		
Not-Technology			Human doings		

One problem we encounter when trying to distinguish science from technology is that the principle actors (scientists and engineers) act very similarly. It once was the case that science was considered to be a noble pursuit wherein the result was simply a better understanding of the world. Scientists, unlike engineers, were not "muddying" their hands trying to make and sell machines. Again, the notion of knowing why and knowing how comes into play here. Yet it is clear that though scientists still concern themselves with knowing why, they are increasingly taking part in projects with practical ends and potentially large financial rewards.

It is certainly still possible to find scientists who are solely interested in learning more about the world. Most astronomers, for example, are simply in search of more knowledge about the universe. They probably will not be turning this knowledge into useful or lucrative technology. Yet many modern scientists are in search of practical solutions and financial gain, whether they work in a university or in business. Do we consider these people to be engineers when they do so?

Table 1.2
Common (*and outdated*) Stereotypes

Science	Interested in TRUTH; Not interested in practical solutions; Not interested in financial gain.
Engineering	Interested in practical solutions and financial gain.

One answer is to simply ask whether a particular person identifies himself more with science or engineering. Here we are taking a *contextual* approach, permitting actors to define themselves. One of the interesting results of this approach is a bias towards science. Engineers who partake in research oriented activities begin to identify themselves as scientists, while scientists, when taking part in engineering activities, continue to identify themselves as scientists. This is largely a matter of prestige; engineering has for many years been considered subservient to science.

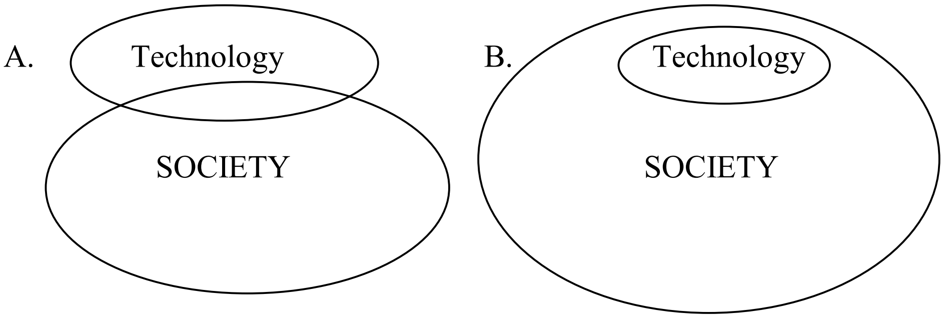
Another way to look at the distinction is historically, but this too has its drawbacks. If we examine science and engineering before the 19th and 20th centuries, it is usually very easy to distinguish the two communities. More recently, for reasons that will become clear, science and engineering are much closer together, and in many instances, indistinguishable. For this purpose, when speaking about recent science or engineering, this book makes little attempt to define exactly which group.

Understanding Technology as a Social Activity

By now you might be more confused than illuminated. One item, however, should not be overlooked. No technology exists in the absence of humans. While we may believe that science describes or models a universe that actually exists (regardless of the presence of humans), technology is always a human activity (in truth, science is no less a human activity). We cannot imagine a wheelbarrow sitting alone in a field in a universe without humans. The reason why the rock in the example above becomes a technology is because a human is using it to his/her own ends.

This simple idea has fundamental implications. It means that we should not consider technology as something separate from society (e.g. dropped down from the sky by engineering gods) but as a social activity. Technology is something we participate in, not just engineers, but all members of society. The technologies we choose to use, how we design and use them, are social functions. As much as people might believe modern technology to be based on objective scientific facts, it is actually the product of social forces operating within natural (physical) limits.

Figure 1.1
Which diagram best represents the relationship between technology and society?



A further implication is that technology, as a human activity, is thus an appropriate subject of study by researchers who normally focus on humans (as opposed to the strictly material). Anthropologists, sociologists, political scientists, historians, etc., are all groups who have something to gain by focusing on technology as a social behavior. Not surprisingly, the results of such research differ qualitatively from how most technologists (engineers, physical or natural scientists) view the world. We would hope, however, that these different perspectives complement each other, though in reality, debates and arguments persist.

A final implication about our definition of technology is that we should learn how society shapes technology. Technology, as a social activity, is imbued with our values. In the same way that we can approach a painting or a novel and use it to explore a particular culture, so too can we take a technology and try to interpret society. Indeed, this is exactly what physical anthropologists do when they examine the technological remnants of early humans. Not only do we want to become adept at interpreting technology, but also understanding the mechanisms that give our technologies cultural value.

Organization of the Book

The first part of this book begins with a brief historical treatment of technology and science. This is partly a matter of personal preference; I am an historian. But as I mention at the start of the next chapter, history has an explanatory power that is difficult to match. Historical data is often a fundamental input to many social science and humanities disciplines. It gives us a strong contextual understanding of where modern technology comes from.

The second unit of the book explores a number of concepts and approaches for modeling technological change. These concepts derive from many different corners of the academic universe. I have tried, as much as is practically possible, to present them in a unified fashion. Whereas the first unit circumscribes technology with historical narratives and specific detail, the second unit attempts to create abstract, generalized models. These are not necessarily contradictory programs.

The third unit returns to a more textured portrayal of technology using three contemporary frames of reference: economics/government, environment, and security. There are an unlimited number of real-world contexts to explore technology, but I believe these to be of the greatest importance. Technology is our major economic driver. Technology is at the center of our environmental conundrums. And technology is crucial to the security (or insecurity) of our local and international communities. Many of the larger questions related to the long-term viability of the modern world hinge on these issues.

The fourth unit takes a decidedly introspective turn, showing how technology is about *who we are*. Like the previous unit, there are a number of ways we can explore this, but I believe that the three I've chosen (politics, gender, and culture) give the greatest bang for the buck. Other areas, such as "technology and work" or "technology and class" are also attractive, but the issues of politics, gender, and culture actually go a long way to illuminating these other areas.

The final unit explores some of our options for reducing our rate of technological failure. You might take this as a kind of indictment of our current socio-technical systems. At the very least, the unit is motivated by the notion that there is always room for improvement. The three chapters that make up this unit can be summarized as follows: making ethical choices, preparing for failure, and establishing a decision making process that is accountable to everyone. I hope that this unit provides a springboard for a life of wise technological decisions.

Academia and the Wider World

There is a scholarly background to this book. It derives, broadly speaking, from the field of science, technology and society studies (STS). In general, I make little reference to the more nuanced scholarly arguments or specialized jargon that is the subject of continued debate within and among the different disciplines that contribute to STS. As an example, even the name "STS" is the subject of debate, with some participants arguing that it should really be "science and technology studies" since science and technology *are* social activities. I quite agree. But in writing a book for a wide audience, I've placed clarity at a premium.

I do encourage you to read more widely on the topics presented in this book. With each chapter I've provided a short bibliography that indicates where I've done some of my research, and where you can go for more in-depth analysis. As an interdisciplinary venture, there are many different avenues for exploring technology within the humanities and social sciences. You should have little trouble finding a flavor to your liking.

Most important of all, I expect my readers to make the effort to connect their lives to the discussions covered in the following chapters. This requires not only a certain amount of contemplation and introspection, but that you fully engage yourself in the world around you. If you don't do it already, begin reading a newspaper every day; current events provide us with our best case studies. Hopefully you will begin to approach the world with a new set of eyes. This book's goal is nothing less than the title, that you begin seeing people in the machine.

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2 History of Technology

Why History?

Students often question the worth of studying history, especially when we are concerned with the future. Furthermore, many students have had unfavorable experiences in primary and secondary school history classes, where they may have been required to memorize innumerable facts (subsequently forgotten) and focused completely on the activities of elite classes. There are two important and inter-related reasons for studying the history of science and technology: explanation and identity.

Who we are, and how we got here are basic questions that we should all be able to answer. As individuals, communities, and nations, history defines us. Our lives, while disorganized and quite unpredictable, do not proceed randomly. The environment that we each faced from birth was shaped by historical occurrences, leaving some paths open to us, and closing others. History thus holds a great deal of explanatory power for understanding our present circumstance. It would, of course, be foolhardy to think that historical analysis can predict the future, but it at least gives us more wisdom about potential historical outcomes. Finally, this history is important in establishing identity, especially for scientists and engineers. Science and engineering are not simply practices learned from textbooks; they are ongoing communities of people.

When studying history it is important, perhaps crucial, to remember that behind the names, the dates, and events, there were real people, not all that different from us. While we may quibble about exact historical details, while interpretive debates will never cease, the people we talk about and the lives they lived were not a fiction. As you think about our past, try placing yourself in the past as well.

What follows is not a comprehensive history of technology – an impossible task for a single chapter. Nor are we necessarily interested in learning every nuance about the subject. Instead the chapter seeks to make a limited number of points about humans and their relationship to technology, as well as locate our own brand of modern technology by placing it in contrast to other forms and traditions. Later chapters will continue to explore important aspects of the history of technology.

Homo Faber: Technology and Human Evolution

Homo faber is Latin for “man the maker.” The phrase has been used by thinkers in different ways, sometimes to distinguish humans from animals, sometimes to highlight aspects of human evolution. While humans are not alone in using technology (we find primitive tool use in chimpanzees), tools and the act of making have been part of human development. In fact, what makes the idea of *Homo faber* interesting is that humans depend on technology like no other animal. This dependence began long ago.

The first thing to note about the development of humans is that certain physical traits appear to have made it easier (or more likely) to use tools. Bipedalism (walking upright), allows us to use our hands for something other than walking. The existence of two bones between the elbow and the hand allows us to rotate objects. Our opposable thumbs permit a tight grasp. Of course it would be specious to argue that these features came about because of, or for, tool use. There is, however, a clear advantage in being a human, over say, a cow, in developing objects that aid our existence.

Yet it is more than just aid. Without tools, humans would live a precarious existence. Our bodies are, in truth, not well equipped for hunting. We lack large teeth and claws. Our bodies are bereft of most body hair, making life without clothing difficult in all but a small number of climate zones. Even if many of our important physical traits developed before the rise of tool use, we have subsequently become dependent on them in an evolutionary manner. There is a debate within anthropology about whether the rise of tools, especially weapons, spurred the change from occasional to continuous bipedalism – a question we will probably never resolve. Likewise, there is speculation that the great rise in brain mass between Australopithecus (3 million years ago) and subsequent hominids, such as *Homo erectus* (1.5 million years ago) came about from stone tool use. The argument for this is that hominids with greater cognitive abilities would have been better at surviving (e.g. defending themselves with clubs and spears) and thus more likely to procreate. The better the tool-maker, the greater the chance of edging out others. Thus it is possible that human evolution and toolmaking codeveloped. Counter arguments explain brain changes as the result of other developments, such as language.

The first definite evidence of tool use dates to about 2 million years in east Africa and may have been used by *Homo habilis* – an evolutionary predecessor of modern man (*Homo sapiens*). *Homo habilis* in fact means, loosely, handyman. Such tools were made by a process called pressure flaking, in which the toolmaker carefully struck another stone to form a sharpened edge. *Homo erectus*, which emerged about 1.7 million years ago, had a definite set of tools. According to Adam Kuper, "throughout its history and in every part of the world in which it has been found, *Homo* *erectus* is associated with a tool kit that is both restricted in range and monotonously uniform." (Kuper, 52)

The evidence to date suggests that human predecessors were not sophisticated hunters, and that they probably spent more of their time gathering vegetables and fruits, with the occasional prize of a dead animal for meat. It was not until the last 50,000 to 30,000 years that we see sophisticated hunting equipment. We also find evidence of jewelry production and musical instruments. These artifacts are strong indicators of culture and suggest that human language was developing rapidly at the time.

The Neolithic and the Built Environment

The Neolithic (new stone age) Revolution is the name applied to the period in history when humans changed from a hunter-gatherer existence to becoming settled farmers. Calling this a revolution, however, is a bit of a misnomer, since it represents a number of changes that occurred gradually and sporadically across the globe. For the sake of simplicity, we say that the Neolithic began 10,000 years ago.

We are not certain of the exact sequence of events (did people first settle, and then farm, or did farming and settling occur simultaneously?). Furthermore, we should not necessarily assume that people who learned to farm did all that much better in food production than people who gathered. There is evidence that farming requires more work for the amount of food gained, but the advantage is that farming is a reliable source of food.

From a technological point of view, the developments of settlements meant a profound change in the use of technology and the relationship between humans and the earth. Instead of living with and among natural things, humans began shaping the world to meet their own needs. *Ever since the Neolithic we have been modifying our environment.*

In addition to a more stable source of food, living in settlements provided an opportunity to create a whole range of artifacts that would have been impractical for hunters and gatherers. Think about it. How much technology could you have if you were constantly moving? For Neolithic peoples, most of the new technology would be related to food production. There would be tools for agriculture (a stick-plow), for food preparation (a grinder), storage (baskets and clay pots), and cooking devices. Associated with all these tools would be a growing body of skills and practices. One would expect that over time the diet would become increasingly varied as people learned about and developed different foods and food preparation methods.

Another important aspect of the Neolithic is the creation of homes. Despite the wide variety of housing types (caves, mud-walled, stone, wood, etc.) most homes had two simple goals: to keep out bad weather and bandits. The first goal meant, in part, that humans could continue to increase their geographic range into areas with more inclement weather. The second goal was very much the result of being settled in the first place. With the accumulation of more artifacts, and the occasional production of surplus food, settlements would have attracted all manner of hungry and greedy persons.

Technology and the Emergence of Political Structures

Eventually, as human settlements grew, they organized themselves into larger social, economic, and political structures. The rise of these civilizations began between 3,500 to 3,000 BC or (5,500 to 5,000 years ago). Many of these civilizations were located around the major rivers of the world, including the Nile, Tigris-Eurphrates, Indus, and Yellow Rivers. In fact there is a strong connection between the rise of these civilizations and the level of technology. That is, the political units that controlled these peoples were often strongly linked to systems of irrigation and water transportation. We call these "irrigation civilizations." In areas like China and Egypt, the irrigation of fields required large amounts of cooperation and leadership, achievable only through strong political control.

It is in this period of time that we see the rise of an artisan or craft class of people. Through much of the Neolithic period we assume that most of the technological knowledge (about farming, food preparation, and tools) was shared by all members of society. With the rise of cities and civilizations, there is an economic possibility for a class of people that are able to make a living by specializing in certain technologies.

Like Neolithic settlements, civilizations provided for new opportunities in the creation of wealth. Civilizations are not merely an agglomeration of settlements. Not only is there an overall productive increase from better land utilization, but the association provided a kind of insurance plan. Depending on how "civilized" the civilization was, we find that some rulers shifted surplus grain to areas of drought or famine. Rulers often devised methods for maintaining central warehouses to keep surplus grain from year to year. Civilizations also attempted to establish social stability through laws and armies. People could spend less time protecting their food and valuables, and more time creating them.

While economic specialization led to the rise of entirely novel artifacts and processes, civilizations also invested greater amounts of time and effort in developing and retaining technological knowledge. As we will see in the following chapter, civilizations were crucial to the development of scientific knowledge.

Nomadic Technology

Nomads are, by definition, any group of people who do not follow a settled way of life. History has not been kind to nomadic peoples, neither in their treatment by "civilized" peoples, nor in the accounts given by historians. The spread of the modern nation-state, made possible in part through technology, has through the late 19th and 20th centuries done much to destroy nomadic culture. And most historians and chroniclers have through the ages come from the "civilized" camp, making for a one-sided view of history. Though no more prone to savagery than "civilized" peoples, Nomads have long been given the name "Barbarian." The decline of Nomadic culture is tragic, for these people have, for much of history, exerted a strong and positive influence.

Nomadic culture is, like civilized culture, deeply tied to specific environments. It is no mistake that humans settled in areas that could support farming. Nomads, in contrast, existed in non-arable lands, areas where regular farming was usually impossible, if not extremely difficult. This included many arid regions – deserts and high mountains. Nomadic technologies, likewise, were uniquely adapted to these particular circumstances. Since non-arable land can support humans only temporarily, nomads perfected a system of mobile technologies. Instead of farming, some nomads hunted (e.g. the Inuit or Eskimo peoples who inhabit the arctic regions) or turned to grazing livestock, usually sheep. Sheep were the principle resource, providing meat, milk, and wool. What the clan did not use immediately was traded for goods.

Instead of staying in permanent houses, nomads perfected temporary housing. The Inuit developed igloos, houses of snow and ice. More typical was the yurt, a tent of wool, leather and wooden poles. It stowed easily on the backs of pack animals. Within the yurt, or nearby, one would likely find a portable loom, from which clothing, bags, and carpets would be produced. Small looms were arranged horizontally on the ground, pegged directly into the soil. Carpets themselves have become a hallmark of many nomadic cultures. Indispensable parts of a nomadic home (they could be found on the floors and walls of the yurt), carpets became objects of trade and cultural transmission. Carpets were not simply utilitarian objects, but designs with deep meaning and clan association.

With such a strong dependence on sheep and beasts of burden, nomads became among the best practitioners of animal husbandry. They understood selective breeding techniques and were probably (since we don't have direct evidence) responsible for helping domesticate sheep, horses, and camels.

Since the clan was always on the move in search of fresh grazing land, nomadic peoples formed links in great trading routes. The Silk Road is a good example, stretching from northwestern China to the Middle East and Eastern Europe. Nomads were thus responsible for much of the technology transfer that occurred before the age of long distance maritime trade. It was not just technology that was being transferred, but culture as well. Notice, for example, how the geographic spread of Islam is closely associated with trading routes.

While nomads probably contributed more to the world through trade, they are best known for developments in warfare. Here we find two important technologies: horses (as domesticated animals) and metals. In many civilized parts of the world, the horse was, until the last few hundred years, considered an expensive luxury. Many farmers preferred oxen, for example, when tilling a field (a misconception arising from poor harnessing techniques for horses). Nomads, however, did find the horse useful – it could carry a heavy load, and was an excellent platform for warfare. Additionally, nomadic cultures were among the first to develop and come into contact with metals such as iron. This was in large part due to the regions they inhabited, such as the Caucuses, mountainous areas that were rich in iron ores. When normally disparate clans rallied behind ambitious leaders, the technological combination of horses and metal was awesome. Nomads routinely swept down out of the arid regions to invade settled peoples. In many cases, the settlers who were supposedly more advanced and certainly wealthier crumbled before the invaders.

Pre-Industrial Engineering

It is often with a sense of bewilderment when we, in the late 20th century, approach an ancient or medieval structure and reflect on how it could be built, *without modern engineering.* How is it that cathedrals could be built to heights of nearly 50 meters using unreinforced masonry – and survive to this day? How is it that the Romans could build a dome with a diameter of over 43 meters, again, using unreinforced masonry? These are achievements that no engineer would attempt today, and not merely because it might be considered unnecessarily unsafe – but because it is too hard.

The truth is that a kind of engineering did exist. There were individuals, artisans, who specialized in a specific kind of technology, and passed this knowledge down from generation to generation through the apprentice system. There were no schools, at least not as we know them now. At a fairly young age, a person would agree to work for (in some cases this was not a matter of choice) and under a master craftsman. They would not learn from textbooks, but on the job by watching and copying. It was a process that, like modern education, took many years. The apprentice would advance slowly to higher and higher levels of qualification. Under the most sophisticated systems of apprenticeship, there were exams – usually practice structures or objects made to prove the students' technical, and occasionally, design abilities.

Apprentice-style education is still used today, especially for skills that require some level of manual dexterity. Consider playing the piano. You can read as many piano books as you like, memorize songs and chords, but until you teach your hands how to dance over the keys, you are not going to become a good pianist. Likewise, learning how to work with wood, metal, ceramics, wool, etc., requires a great deal of practice in order to teach our bodies how to express the designs we have in our head.

Very often the artisan and the exam system were organized as part of a guild structure. In some ways, guilds are similar to modern trade organizations. In organizing themselves artisans could increase their economic and political power within cities. The main method of doing so was by limiting access to technical information, as well as restricting who could enter a particular trade. As carriers of highly specialized information, artisans within a guild could control a particular market and demand higher prices for their work. While this gave many guilds a monopoly power, they were also beholden to maintain high standards. That is, for the sake of their trade, they had to maintain high quality in their workmanship, something they achieved through the apprentice system and the examinations.

We need to be careful when we say that artisan technology was non-scientific. Artisans and guilds did generate useful knowledge about the world, and they had some methods for establishing new knowledge. One of our problems in looking back at these old technologies is that it is nearly impossible to reconstruct what artisans actually knew (since they rarely wrote it down – it was often secret). It is clear, however, that there were formulas and rules for doing things. Such rules were based on experience, on what had worked before, or what had been attempted and failed.

We can take a single example from late Medieval Europe, the cathedral builders of France. The 12th and 13th centuries were a period of cathedral building, and great strides were made in a very short period of time. We do not know how these builders came to have an understanding of stress and loading, but they somehow learned enough that they could design very large structures that tested the limits of their materials. We do know that they had methods of experimentation that depended on learning about the structure as they built it. We do not have records of the formulas they used, or the reasoning behind these "building codes."

In the case of China, as I will discuss in chapter 9, there was a set of building codes. Again, while these are not scientifically derived or based on ideas that would agree with modern mechanics, it does not mean they are wrong. In fact, the design guidelines often give very good approximations to that actual limits of the materials and structures they were building.

As a matter of symmetry, it is worth mentioning one of the drawbacks of craft/guild technology. The most obvious is the degree of conservatism expressed in these designs. Bound largely by observational experience, craft designs tended to evolve in an incremental fashion. When something new was found, as in the use of flying buttresses with Gothic cathedrals, craftsmen only gradually increased the heights of their churches. Over a 100-150 year period they eventually found, through experience, the practical limits of this design.

The Industrial Revolution: Changes in Economy and Technology

One of the biggest changes in the history of technology was the industrial revolution, which occurred between 1750 and 1850 in England. The industrial revolution is actually difficult to define since it was not a single event, or focused on any single technology. In fact we can find precedents to the industrial revolution elsewhere, such as in Holland and Italy, and China, at times, certainly had the makings for an industrial revolution. Recognizing that we are simplifying the story, we'll say that the British industrial revolution was the first. And it certainly was dramatic as industrialization goes. It involved large increases in production (both agricultural and industrial), a significant rise in population, urbanization, and the use of the factory system.

The factory system gradually replaced older forms of production, especially the "putting out" system. In putting out, materials were taken by a merchant to the individual homes of skilled workers. There the raw materials would be turned into a finished product, which was collected after a week or two. The workers were skilled, largely unsupervised, and worked at their own pace. It would be customary for the workers to keep some of the raw material so that they could make things for themselves. The factory system changed this by placing the workers in one building. They were regulated and the materials were highly controlled. The work was divided into small jobs, which were mechanized if possible. The workers did not require much skill, which meant that the factory owners could pay less. The mechanized work processes were often connected to a central power source, perhaps a waterwheel or a steam engine.

The factory system was itself a technology. And as such you should start to see it as both a powerful social force, and as an expression of social forces. In this case we see that it created profound change in the way people lived and worked. In most cases we could say that there was deterioration in the quality of life. Additionally, we see that the factory system was the expression of a capitalistic economic system. The means of production were under the control of a small elite group of factory owners. Their interest was making money, not building a better quality of life for the workers.

The industrial revolution is associated with a number of other technologies, including iron production, railroads, textile, and chemical manufacture. Many of these technologies contributed significantly to the increase in water and air pollution, as well as changes in the landscape (such as deforestation).

Industrial Science

One might ask about the role science played in the Industrial Revolution. The answer is complex. On the one hand, many of the same developments that were occurring in science in the 17th and 18th centuries were also taking place in specific fields of technology, such as hydrology, mechanics, mining, and ballistic. On the other hand, many of the technologies of the industrial revolution arose without strong scientific underpinnings. Many engineers and artisans simply could not use the findings of science to elaborate their own work. We might hypothesize that the industrial revolution might have occurred in the absence of scientific developments, but doing so ignores the common social, political and economic changes that gave rise to both these historical movements.

Nevertheless, it is not until the late 19th century that there arises a widespread and concerted effort to apply science to the development of new technologies (as opposed to earlier more sporadic efforts). Yet the influence is not necessarily in ways we think. The most profound crossover from science was not theory, but in the methods of experimentation, measurement, and mathematics. Engineering was transformed into a scientific discipline. To a lesser extent, engineers made use of scientific theories, but in many cases, such theories remained either too confusing for many engineers, or simply to general and abstract to apply to real world conditions.

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3 History of Science

The very idea of a history of science suggests that we can define a single scientific tradition that extends back through time. This is problematic, since the practice and practitioners of science have changed dramatically. We can even trace multiple and simultaneous historical scientific traditions within different cultures. And if we go back to what is considered the beginning of science, a few thousand years ago, there is little to suggest that those origins would logically result in the science of today. In part these difficulties result from the varied definitions of science. Are we referring to a community of people, to a tradition of practice, or to a set of ideas? We tend to mix in a bit of all three in our attempts to provide a cohesive story.

So if there is no single, grand history of science, what is there? We may begin with the assertion that what we think of as science is a modern phenomenon, and here we use the word modern in its broadest sense, to indicate a development of the last few hundred years. It is a phenomenon located very much in Europe, defined by some basic commonalities in practice, related communities of practitioners, and an interconnected (though varied and often conflicting) intellectual tradition. This modern phenomenon does have ancient roots, but it is preferable to say that a number of ancient practices and ideas deeply influenced the rise of science.

We must emphasize that scientific practice is also a cultural practice. Thus we find that in addition to Western science, there are other variants. China is the most notable example, in part because aspects of Chinese science (especially medicine) coexist with Western science. The persistent difficulty of integrating Chinese and Western science is not due to an inability of one to integrate the knowledge of another, but conflicts of scientific culture. All of this may strike us as very odd, since practitioners of Western science nowadays not only come from many different cultures, but we are taught that science is objective (and thus culture-free). Certainly, modern science aspires to objectivity, but no social activity can ever be culture-free.

That modern science is a cultural activity should not reduce our respect for it. True, there are many communities of people and practices which attempt to explain how the world works (palm readers and astrologers), but science appears to work better than any of these other activities. It behooves us to ask why this particular activity provides more reliable information than any other. What is so special about it? The attempt to investigate the world (without prejudice) suggests part of an answer.

Origins of Western Science

Keeping the aforementioned caveats in mind, our description of science begins in ancient times with the development of mathematics and astronomy, and the rise of inquiry into the natural world. These activities were not unique to the west, but they formed an important element in what would later become science. It is also important to point out that though Western science was ultimately a European phenomenon, the ancient influences came from the Middle East and the eastern Mediterranean.

Our story begins in Mesopotamia (the region of modern day Iraq) approximately 3500 to 4000 years ago. Here developed a fairly sophisticated mathematical system that we refer to as Babylonian math (after the city of Babylon). It utilized a base 60 numbering system (it was thus a place value system) written in cuneiform (wedge shaped). While they made use of other bases (24, 12, 10, 2), for astronomy and mathematics sexagesimal was the primary base. There are certain advantages to Babylonian sexagesimal mathematics including the ability to work easily with fractions (60 being divisible by 2, 3, and 5). This utility led to numerous cases of adoption by different cultures for astronomy, including Greece, Islam, India, and Europe. We can see the survival of the sexagesimal system in time keeping (60 minutes/seconds), as well as the compass rose (360 degrees) and geographic positioning (minutes and seconds). Babylonian mathematics did not have formal proofs, but they did have procedures for solving many problems (including quadratic equations) and appear to have understood the ideas behind what would later be called the Pythagorean theorem (this some 1200 years before Pythagoras). While most (if not all) daily activities in antiquity were well served by simple mathematics, more sophisticated computations found use almost exclusively in astronomy. (Neugebauer; Aaboe) Babylonian astronomical predictions were fairly accurate. The Babylonian's were not alone in this achievement, but they did so through arithmetic means. This is important in understanding the development of science: that natural change can be measured and understood through mathematical analysis.

The Greeks adopted much of Babylonian mathematics, though it was probably learned in bits and pieces over time. The Greeks, however, used the Babylonian system primarily for observational astronomy. The Greek contribution to math lay in something quite different: the development of theorems and proofs, primarily geometric. The flowering of Greek math occurred approximately 300 to 200 BC. Euclid, living at this time, wrote the *Elements*, a treatise that would be immediately recognizable to anyone who has taken a geometry class. It utilizes the familiar system of proofs beginning with postulates. The *Elements* is exhaustive in its treatment of geometric theorems, representing not only Euclid's ideas, but those of his intellectual forebears as well. The *Elements* also includes algebraic principles, but expresses them typically in geometric proofs (including the quadratic equation).(Aaboe) Archimedes, living slightly later than Euclid, produced numerous original works in mathematics, mechanics, and engineering. Among the developments you would probably know are the area of a circle and volume of a sphere.

Thus the Greek's developed a clearly geometric understanding of the world. While this was not necessarily accurate in predicting when things might happen (indeed, Babylonian arithmetic was sufficient for that task), it explained *how* things occurred. More precisely, geometry permitted the Greeks to create plausible models for how things might occur. There is a fundamental quality of inquiry bound up in this. Though the Greeks had recourse to religious explanations for change, they attempted to understand the world as something that operated according to knowable rules. Geometry, and the mechanics of geometric shapes, provided a guide for how things worked. For some Greek scholars, the world and the geometric model were one in the same (e.g. thinking that the world was made up of triangles). For others, geometric models were just that. Finally, geometric proofs, like numbers, held the attraction of being self-evident. That is, they did not require recourse to outside opinion. The method of bisecting an angle was as certain as two plus two was four.

Among the more long lasting developments within Greek science was the *Almagest*, an astronomical tract written by Ptolemy (an Egyptian scholar) in about 150 AD. It used a geometric approach to the movement of the stars. And through trigonometry it showed how the movement of the heavens could be calculated. Ptolomy's model placed the Earth at the center of the universe. Retrograde motions (when planets appear to stop and move backwards relative to the apparent star field) were explained through the use of multiple circles (epicycles). The Ptolemaic system would remain the dominant understanding of the stars (in the West) until the advent of the Copernican system in the 16th century.

The next significant contributions to western science came with the rise of Islam. Islam originated from Mohammed (569-632) and spread rapidly throughout the Near-East – the same areas that much of the previous scientific activity had taken place. Islamic scholars eventually translated many of the ancient Greek texts into Arabic. They kept these traditions of thought alive, while at the same time contributing very significant methodological and theoretical approaches. In the 9th century, for example, they developed algebra (more specifically, Al-Huwarismi wrote a book entitled *Algebra*). For a period of about 500 years, Muslims were the preeminent scientists.

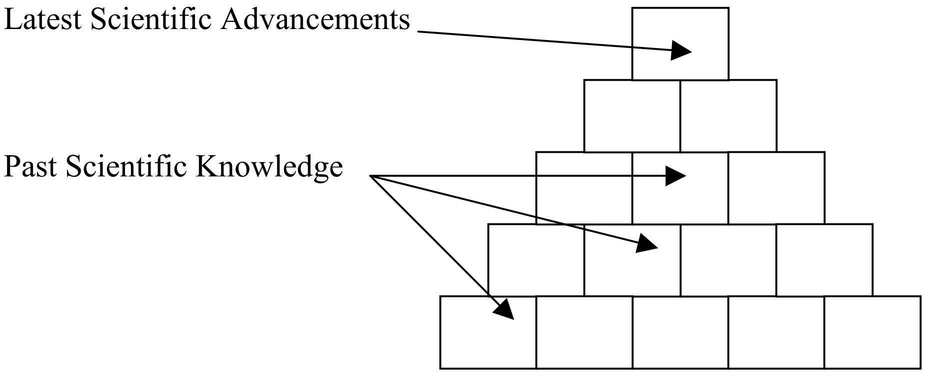
Science in Europe

It is only with the political and economic rise of European countries in the 12th and 13th centuries that scientific activity shifts west away from the Near-East. In this period and in different places throughout Europe, new urban schools emerged that taught classical subjects. They revived ancient Greek and Roman texts (including those in science). In many cases (especially in relation to scientific tracts) Europeans had to translate these texts from Arabic (since the original Greek texts were gone). As time passed, schools turned into universities, and European scholars began making their own contributions to understanding the world. These universities existed very much within the confines of Christianity. Learning that originated outside the Christian tradition (e.g. Pagan texts) was permitted in so far as they could be used to further Christianity. One of the results of the dominance of religion was that scientific debates often centered on how there could be philosophical resolution between religious convictions and scientific thinking. Scientific arguments were in many cases abstract philosophical assertions that made scant use of available evidence from the natural world. This would change dramatically in a movement that we now call the Scientific Revolution.

The Scientific Revolution was quite unlike a political revolution, occurring not in a matter of days, but over decades. The movement was so gradual that historians debate whether revolution is even an appropriate name. It took place in the 17th century, and is marked by radical change in the way people pursued knowledge about the world. It was characterized by the development of experimentation, measurement, and mathematical analysis. All three of these methodologies could be found in earlier times, but what happened at this time was unique. Combined, they became the basis for resolving debates among communities of scholars. Inquiries into the nature of the world were thus solved not by the dictum of powerful people and institutions (though they remain influential in scientific debates to this day), but through agreed upon procedures (measurement, mathematics, and experimentation) meant to lay bare the workings of the world.

Thus we have the beginnings of what we might call, loosely, a modern scientific process. We need to remember, however, that this is a social process: scientific validity is not based on any intrinsic truth, but on the public acceptance of an observable experiment. Additionally, the content of science (scientific facts) changes from generation to generation. It is interesting to see that over the course of four hundred years, the process produced a great deal of what we now consider incorrect knowledge (if we can take our modern understanding of the world to be the correct one – a naïve and conceited assumption). This begs the question: if a process could be so wrong, why did it turn out so valuable? In part, we need to see the Scientific Revolution as a combination of methodologies and debate within and among communities. Natural philosophers might arrive at an incorrect conclusion, but the nature of scientific inquiry permitted re-examination. Change within the scientific community occurs as scientists with new ideas attempt to convince the larger community that the old theories (or facts) are wrong. It is thus improper to think of scientific knowledge as a set of building blocks built up over centuries. In fact, new knowledge often displaces, rather than complements, old knowledge.

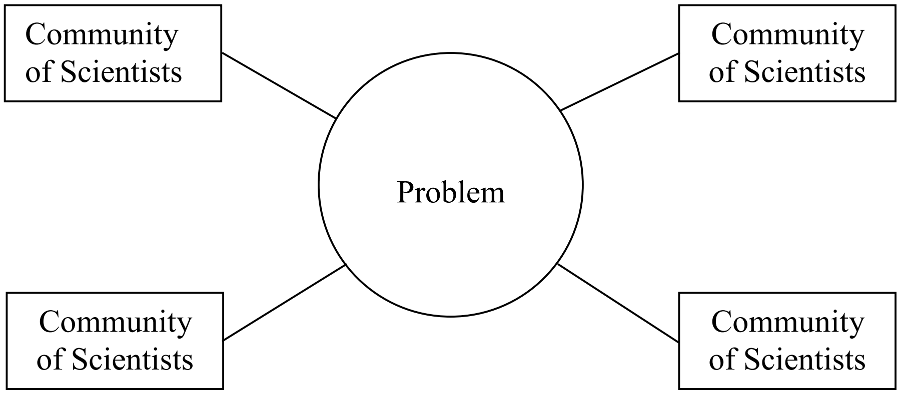
Figure 3.1
Building Blocks of Scientific Knowledge
This portrayal is **incorrect** because it assumes that past scientific knowledge and theories were accurate.



Western science, as a struggle between communities of people, is thus a public activity. The methodologies of scientists are like a set of rules that ensure everyone is playing the same game. An experiment performed in one part of Europe needed to be reproducible in another part. The use of measurement and quantitative reasoning is an appeal to objectivity (though subjectivity creeps easily into numbers and calculations). Experimental methodology, likewise, attempts to identify and isolate only those factors that influence specific outcomes. In so doing, scientific communities can debate the logic of given hypothesis and their experimental results.

As such we can see how Western science does not fit well with non-western science, such as Chinese medicine. Chinese medicine comes out of a different knowledge producing tradition, and does not rely on the same community-based knowledge verification methodologies. It is not just that Chinese medicine has produced different knowledge, but the production of that knowledge is incompatible with established Western scientific traditions. It is no surprise that western science has not accepted much of Chinese medicine.

Figure 3.2
Scientific Change is the Result of Competing Communities of Scientists



It is important to understand that the Scientific Revolution took place within a very specific political, economic, and social context. Europe, at the time, was undergoing significant economic expansion, which had the effect of permitting a small fraction of its population to take up scientific exploration. While some intellectuals were part of university structures, others were wealthy individuals who had the free time to experiment. Just as important, the centers of learning were scattered across different countries of the European continent. While these different centers were connected by active trade routes and good communication (especially after the spread of the printing press), they were also competitive. This cooperation and competition fostered a wide variety of ideas, ideas that were quickly verified (or proven false) by peers in another country. Since different thinkers worked underneath different political (and very often different religious) systems, no single authority could enforce any lasting scientific dogma. Finally, the rise of scientific practice, with its emphasis on rationality and publicly verified experiments, grew at a time of widespread movement towards rationality (effecting, for example, politics and economics).

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Part Two

Creation and Change

4 Technological Networks

Over the past few decades, scholars from many fields have taken a keen interest in technological change. This is fortunate for us as we embark on our study of technology, since we have at our disposal a number of well-developed concepts and ideas. We can appropriate these ideas for our own use. Just as we would use a hammer, screwdriver, and pliers to take apart a machine, so too we can use these concepts as tools for taking apart the complex social process of technological change.

What I present here is a collection of concepts from political science, history, sociology, and economics, all of which we should keep in our "toolbox." Concepts, models and definitions may not be very interesting in of themselves. Learning about a concept does not necessarily teach us much about the real world. The point however is to master a few tools that will help us analyze technology. At some point we need to stop looking at technology from a distance – we have to walk up to it, grab a tool, and start cracking it open. These tools help us understand the technology more deeply, and they help us ask questions in order that we may anticipate future issues. And just like real tools, these concepts only work in certain situations. A hammer is good for pounding a nail, not for tightening a bolt. Likewise, you will encounter situations where you will try to apply one concept, only to find that it really does not shed light upon the issue. Most importantly, these concepts will provide you with different perspectives about technology. For example, there is no conceptual tool for telling us whether a technology is good or bad. In fact, you will find in some situations that the same tool can help you argue that a technology is both good and bad. In so doing, however, these tools give us a deeper understanding of the underlying technology, helping expose the complexity of its social underpinnings.

In bringing all these concepts together from different fields, I have decided to group them into three chapters. The first, this chapter, looks narrowly at the operation of what I term "technological networks." In a very simple way, we want to explore the operation of technology in its more technical aspects. The next chapter integrates the social and the technical, again attempting to see how these combined networks of people and things behave. Finally, the third chapter of the unit is a micro-level examination of invention and innovation.

Insofar as technologies are never isolated technical operations, this chapter is a bit of a fiction. It contradicts one of the main thrusts of this book: that technologies do not exist outside of a social context. But as a way of isolating our perspective, this conceptual approach is still useful.

Do artifacts have rules?

It goes without saying that artifacts are bound by the same physical forces that apply to all things throughout the universe. Gravity does not make distinctions between a human, a machine, or a rock. These physical properties are not insignificant. Technologies *work* because they manipulate physical conditions. Nor do we have the luxury of deciding when physical rules are to be in effect. Try as we might (and indeed, as many have attempted over the centuries) we will not produce a perpetual motion machine (one that produces as much or more energy than it consumes). Such laws and relationships are, of course, the focus of scientific and engineering disciplines. We wish to go further. Are there rules, or at least generalizations that we can make about technologies beyond our basic scientific or technical understanding?

For starters, let's imagine for a moment that we have the ability to travel back through time. We decide to take an automobile and drop it off in the year 1000 A.D. Let's say that we go to the trouble of teaching someone about how to use the automobile. What is going to happen? One of the first problems is that we would not have any good roads to drive the car on. There were roads in the year 1000, but they were made for ox-carts and horses – hardly the kind of thing to accommodate our modern automobile. The second thing that will happen is that we'll probably run out of gas. There will be no gas stations to fill the car. And even if we did find a source of petrol, we would not be able to repair the car if it broke down. How would we repair a tire at a time when synthetic rubber and vulcanization were not known? How would we create the steel required to make engine parts? Where would we get the chemicals necessary to make the lubricants that the car needed? When we talk about a technology, like the automobile, we tend to think of the physical artifact in isolation. We see the car as a thing with an engine, doors, four tires, and a steering wheel. But it should be painfully obvious that the car is part of an entire system of technologies.[1]

Inputs and Relationships

We may say that most technologies require other technological inputs. This is true for almost all but the most basic of technologies. The example of a rock as a weapon (from chapter one) is one such exception. Yet if we

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[1] The following sections are substantially inspired by the work of Nathan Rosenberg and Robert Heilbroner. See the bibliography at the end of the chapter for references.

consider the technologies of early humans (as in chapter two), we see that they were already depending on technological inputs (the creation of stone "tool kits").

Figure 4.1
Technological Inputs

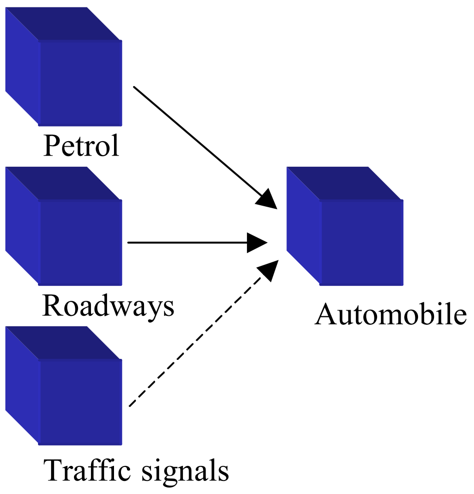
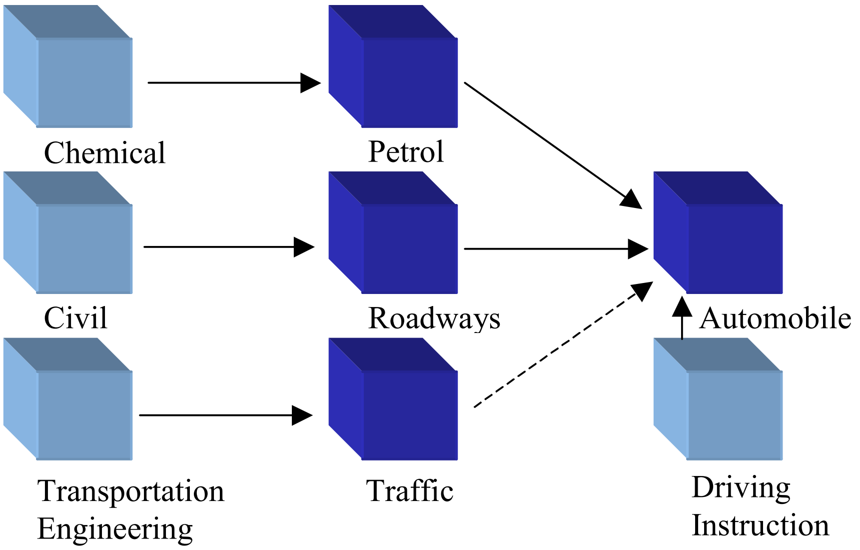


Figure 4.1 illustrates in a very simple manner a few of the many inputs usually required for the operation of an automobile. Of course we can go about altering the automobile so that it does not require roads (i.e. an "off-road" vehicle), require petrol (i.e. a solar car), etc. Usually, however, such alterations merely exchange one input for another, rather than eliminate them entirely. The salient point is that the vast majority of our technologies work only in the presence of other technological inputs.

Consistent with our original definition of technology, we may redraw figure 4.1 to include the technological knowledge associated with the automobile. Figure 4.2 is, again, a simplified view; there are hundreds of different technological inputs to a car, and for each one, a specialized field of technological knowledge.

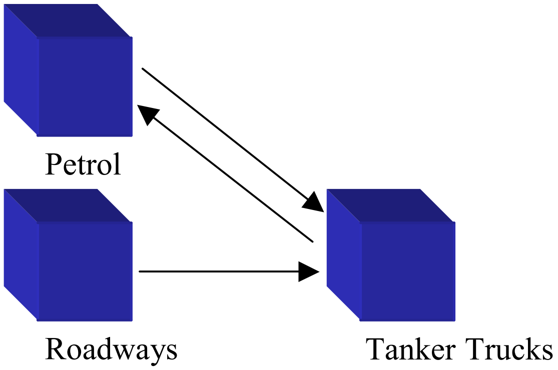
We also want to consider the nature of some of these input relationships. They are not all the same. In some cases the input is required; try as we might, our automobile is not going to operate without fuel. This would be a case of *technological dependence.* Some of the inputs are not strictly required; our automobile will operate without the traffic signals. Of course, in the company of many other cars, we will move much faster with signals. So technologies that are not required, but help improve performance or capabilities are called *complementary*. The point about capabilities should not be missed. If we combine the Internet with encryption software, the result is not a faster network, but one that does something qualitatively different (transfer information in a secure manner). I've indicated complementary relationships in figures 4.1 and 4.2 with a dashed arrow.

Figure 4.2
Expanded Technological Inputs



Our model of technological inputs is also oversimplified in that we have tidy unidirectional arrows. In truth, some of these arrows end up reversing direction if we focus on a different technology. For example, the petrol that we purchase for our cars, usually depends on tanker trucks for final delivery. Tanker trucks have all the same inputs as automobiles, yet they are also an input to one of their own inputs! We might think of this as a kind of *feedback relationship*. The British industrial revolution provides an interesting case of widespread feedback relationships. Steam engines required coal to operate. Miners used steam engines extensively in the extraction of coal. Steam engines required iron in their construction. Iron manufacture often employed steam engines. Iron production required substantial quantities of coal. In terms of economic growth, such relationships lead to mutually reinforcing patterns of demand. In terms of technological growth, these relationships often lead to mutually reinforcing patterns of technological knowledge. The next example bears this out in relation to complementary technologies.

Figure 4.3
A Feedback Relationship



Let's imagine, for the moment, two technologies located in the same city: a bus system and a subway system. The picture of our bus system will be analogous to our automobile example (figure 4.2). The picture of the subway system is shown in figure 4.4. When we consider the relationship between the subway and the bus, we understand that the two technologies are not dependent upon each other. Typically, they are complements of each other, with subways serving densely travelled routes, and buses serving as feeders to the subways. The relationship I really wish to emphasize, however, is occurring in the knowledge areas. Namely, the civil engineering that goes into building roadways (including tunnels and bridges) is largely the same civil engineering that goes into building subway tracks, tunnels and bridges. The illustration of knowledge sharing might appear banal at first, but it has special significance in the development and transfer of new technologies. This will become clearer in later sections, but one of the important aspects of places like Silicon Valley is that while this geographical area produces a number of different products (software, CPUs, routers, PDAs, etc.), they share in common a number of fields of engineering and science. Likewise, many of the technologies of the British industrial revolution had common knowledge components.

Figure 4.4
Expanded Technological Inputs

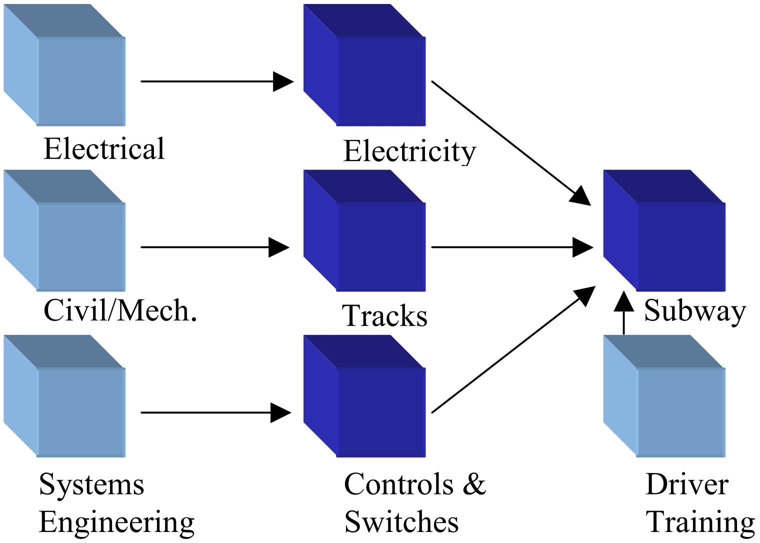
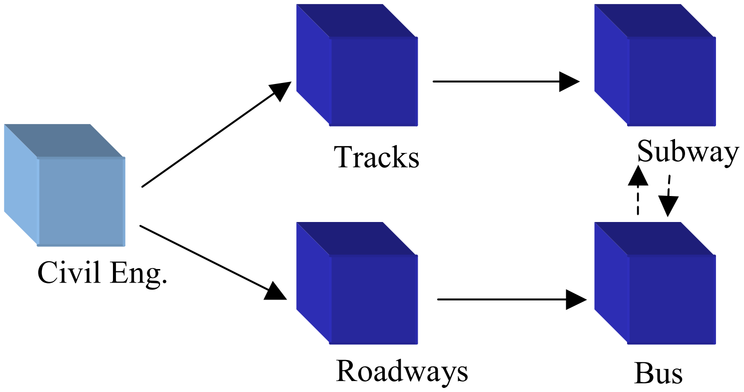
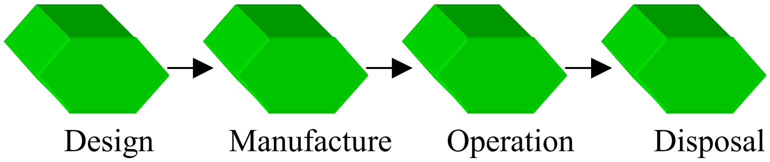


Figure 4.5
Knowledge flows between different technological systems



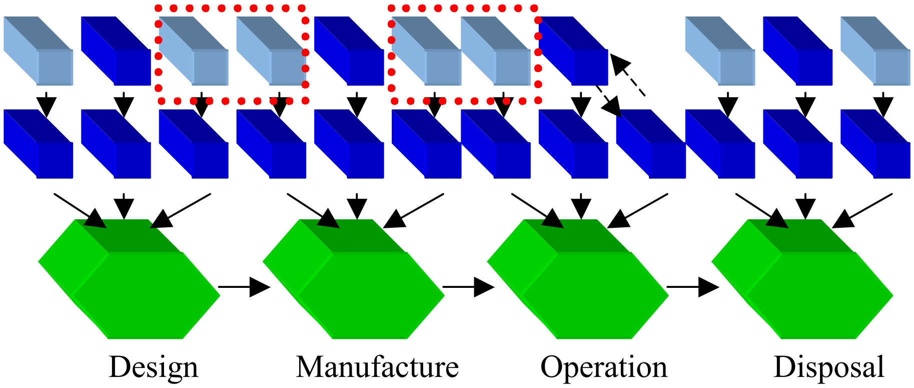
Before launching into a discussion of what these relationships mean, I want to add in one more pattern to our technological model. What we have been examining so far are technologies frozen in time. Broadly speaking, though, we find that technologies come and go, but they don't simply burst into existence; they follow a kind of development, which I've grossly simplified in figure 4.6.

Figure 4.6
The life and death of a technology



Of course, for mass produced technologies the design stage is not repeated for each artifact. I should also mention that this life-cycle is not the same as a product life-cycle, which you might have encountered elsewhere. The point I wish to make is that our models for the automobile and subway examined only the operational stage. We never considered the design, manufacturing, or disposal of a car or subway train. Were we to include all these different stages, each with their own set of inputs, we would end up with something like figure 4.7.

Figure 4.7
Inputs to an artifact's life-cycle



Analysis: what are the implications?

You may have decided that all these little squares, arrows and hexagons have no end, that we can reproduce them adnauseam. That isn't a bad start. When we begin to put everything together, not just single technological systems, but all the different technologies that make up our world, we would arrive at a picture that couldn't be accurately portrayed on this two-dimensional surface. In our imagination, however, we can recognize that our technological world is highly integrated. Technologies are not isolated artifacts; they form interlocking networks of things and knowledge. Changes in one area of the network will ripple across and influence other technologies.

Our model also has a more subtle suggestion: that technologies do not arise or occur randomly. Not only would we have difficulty operating an automobile 1000 years ago, it is inconceivable that any culture in that time period could have produced such a technology. There appears to be a logic to technological development, that we have gone from walking on foot, to riding horseback, to riding in carriages, to driving automobiles, to flying in airplanes, and now to flying in spacecraft. That technologies require certain inputs means that you've got to have those inputs beforehand. There is some anecdotal evidence for this in the form of *simultaneous inventions*. It is often the case that the same invention appears about the same time, but in different parts of the world. At the beginning of the 20th century, for example, there were many groups working on inventing a practical airplane. A crucial technological input, the internal combustion engine, was available to many inventors. If the Wright Brothers had not invented their airplane in 1903, others would have done so anyway. Indeed, most other inventors were scarcely aware of the Wright Brothers' achievement. We also see examples of technological change in how we make predictions about future technologies. My favorite example is Moore's Law, which really isn't a law so much as a prediction. In 1965, Gordon Moore stated that the number of transistors on CPUs would double every 18 months.

Our analysis starts to become very interesting when we recognize that this logical and ordered development of technology might be having a profound impact on human development. This isn't so much of an intellectual stretch. We understand implicitly that technologies define many of our human capabilities. Technologies define economic conditions and economic relations. Technologies form the basis for military strength and, thus, the formation of nation states and the development of international relations. I could go further (and will later in this text). If technologies follow a kind of trajectory (based on the logic of technological inputs and relationships) then might it be possible that this trajectory is a fundamental determinant of larger human development? This line of argument is called *technological determinism*.

If we look at how society thinks and talks about technology, we find that technological determinism has a wide following (even if most people have never heard of the phrase). We often hear the line, "impact of technology on society or the environment," but how often do we hear the reverse, "society's impact on technology." Technology always has agency, and society is the passive victim or beneficiary. Consider something like air pollution; how many of us actually decided that we wanted to choke on automobile fumes? In the world of technological determinism, the machine is king. All those inflexible inputs and relationships form a network that defines what we are able to do as a society, as well as a web that traps us, limiting our ability to create and use technologies as we please.

The inflexibility of technological networks often gives us the feeling that we are powerless to change its course. Not only do we see a logic to how technology has developed in the past, so we see a logic for its future development. But this step-wise movement is internally ordered by the technology. We are not in control of our future, the machinery of our world is! This is a topic that we will return to in the last chapter of the text.

Evaluating Embedded Technologies

Whether machines or people are in control of the future, there is little denying the embedded nature of technological systems. This has real implications for how we approach and evaluate individual technologies. The value of a technology to a society can be termed its *social payoff*. It is a measure of the benefits typically to an economy, though we can also measure the benefits in terms of things like beauty (something that has no easy dollar cost equivalent). The social payoff, or value of the subway really cannot be calculated separately from the bus system. The subway would be much less valuable if there was no bus system. Likewise, the bus system would be less valuable if there was no subway. So we really cannot think of the subway as having a quantifiable social payoff, because it depends on a larger network of technologies, including taxis, buses, regional trains, airline routes, etc. The social payoff of the whole network is actually greater than the sum of the parts.

The point about both complementary technologies and technological interdependence is that if we are going to study technology, we cannot be content to look at the individual pieces. We must consider how they are inter-related. From a design perspective, it would do engineers, scientists, and business people well to understand that when they design, make, or market a technology, it will find its application as a constituent part of a larger network of technologies.

Thomas Edison is mistakenly known as the inventor of the light bulb. Actually, the light bulb had already been invented. What Edison developed was an entire technological system, including a light bulb that worked along with a number of other technologies, including a central power station with generators, a transmission system, and a metering system. Edison realized that the light bulb was no good without the other technologies – he implicitly understood the lesson of technological interdependence.

When we see that there is a social payoff, we should immediately begin to think about whether there is a *social cost*. The social cost of an automobile must take into account all the costs associated with building the roads, production of the car, petroleum production, steel manufacture, and chemical production. Cars begin to pollute the environment long before they are driven out of the factory, long before they are placed on the roads in our cities.

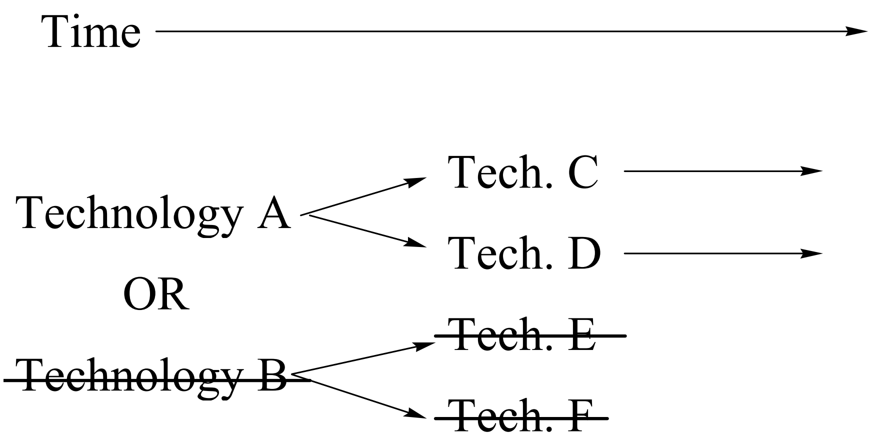
Path Dependence

Our last concept and one that provides a convenient segue to the next chapter is the idea of path dependence. Already we've talked about technology following a kind of trajectory – a predetermined course. Path dependence is the idea that society gets stuck following a certain technological path even when it sees that there are preferable alternative technologies. You can already see how this fits nicely with our present discussion.

Path dependence may arise under at least two scenarios. The first scenario is that society begins using a particular technology, and then another, potentially preferable technology arises at a later date. In the second scenario, there is an initial choice between two technologies. In both scenarios there is some change of conditions such that the original technology is no longer the preferred technology, but (and here is the critical part) due to practical limitations, society is stuck with the original technology (or derivatives of the original technology).

Let's consider figure 4.8. Initially we make a decision between technology A and B. We cannot choose both! Most of the time we do not have the resources to follow two technological paths. As time goes by, our initial technological decision will make technologies C and D available to us, while precluding the use of E and F. Perhaps A is a technological input to C and D.

Figure 4.8
Path Dependence



Let's consider a specific example: driving on the left-hand side of the road in Hong Kong. A long time ago, when people first began driving automobiles, the British decided that they would drive on the left-hand side of the road. At the same time, many other countries decided to drive on the right-hand side of the road. Hong Kong, as a British colony, drove on the left-hand side. In 1997, the British returned Hong Kong to China, which, very inconveniently, drives on the right-hand side. Has the city switched its driving along with its political orientations? No. Such a change would require exchanging the left-hand drive cars with right-hand drive. It would require different signals and signs. It would require changes to the roadways. Most importantly, it would require new driver training. It is possible to make the change, but this assumes that we have all the money and time in the world to do so. In the real world, resource constraints keep us tied to particular technological systems.

A classic example of path dependence (though one that intellectuals continue to fight over) is the QWERTY keyboard. QWERTY refers to the arrangement of keys that one finds on most computer keyboards and typewriters. The QWERTY arrangement, designed in the 19th century, is not optimal in terms of human typists – it places rarely utilized keys in some of the best positions, and frequently used keys in far out positions. It does this in order to slow down the typists in order to keep the machine from jamming mechanically. In the 19th century, QWERTY was an optimal match between typist and typewriter.

In the following decades, typewriter mechanisms improved and new key and faster key arrangements emerged. The QWERTY technique, like driving on the left-hand side of the road, was an embedded standard. The technique prevented the acceptance of faster typing systems. Nearly a hundred years after the development of typewriters, we have computers that use the QWERTY keyboard! Of course, you may individually choose to switch to a different keyboard layout (and encounter no end of difficulty as you move about using computers that are not set up like yours), but a wholesale shift away from QWERTY would involve more time and money than is worth spending. The cost of doing most likely exceeds the benefits productivity gains from non-QWERTY designs.

I mentioned that path dependence is a convenient bridge to our next chapter. This is because path dependence typically hinges on a set of economic priorities. If society wanted, we could indeed switch to a different keyboard layout. But it isn't worth the cost! This suggests that machines, though very important in defining our capabilities and limiting some of our opportunities, are not the sole determinants of technological trajectory.

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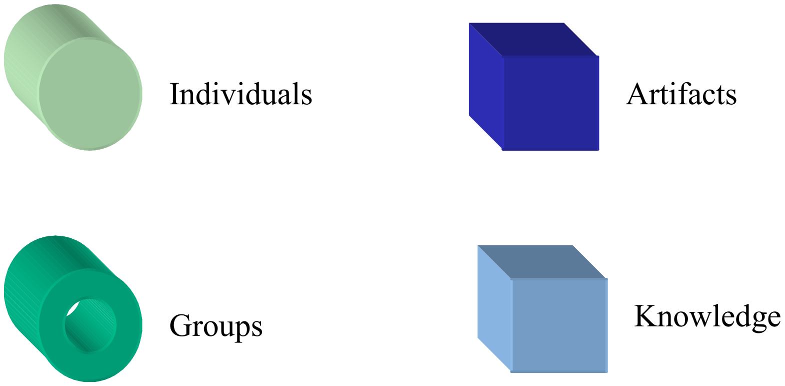
5 Socio-technical Networks

The previous chapter emphasized artifacts and technological knowledge, exploring the relationships between these elements and drawing conclusions about how technology evolves. This picture is incomplete because we have excluded most of the human inputs. We want to go further to understand how technology is constituted within a human network.

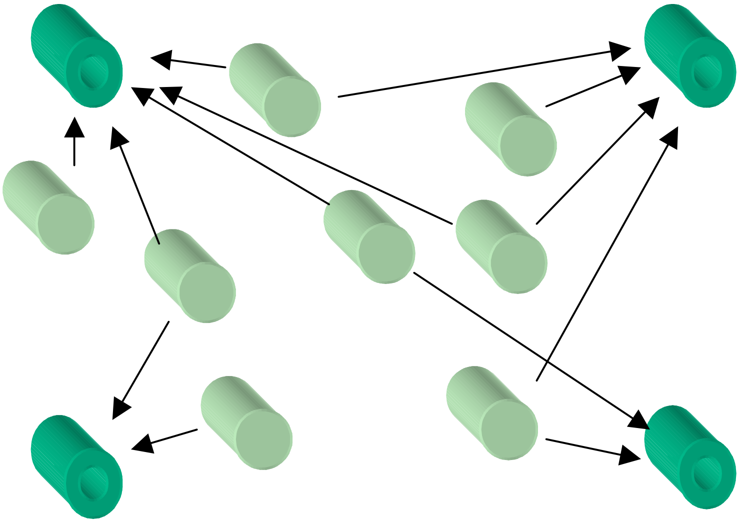
In constructing a more integrated model we will begin by adding two new elements: individuals and groups. A group is obviously made up of individuals. We all have multiple group associations, including family, gender, community, ethnicity, nationality, etc. These group identities criss-cross and overlap. Figure 5.2 provides an over-simplified map of a social network.

Figure 5.1
Elements of a Socio-technical Network



Relations between the different members and groups within a network are governed by norms, rules, and obligations. For example, within a family there are certain expectations about how one should behave as well as the different roles we each play. A business is a different kind of social grouping, and its relations with other businesses are usually explicitly defined in legally binding contracts. We could, if we chose, attempt to specify and signify all these different types of relationships in our model, but it would become burdensome. It is sufficient to note that the lines and arrows among individuals and groups signify an active relationship of some sort.

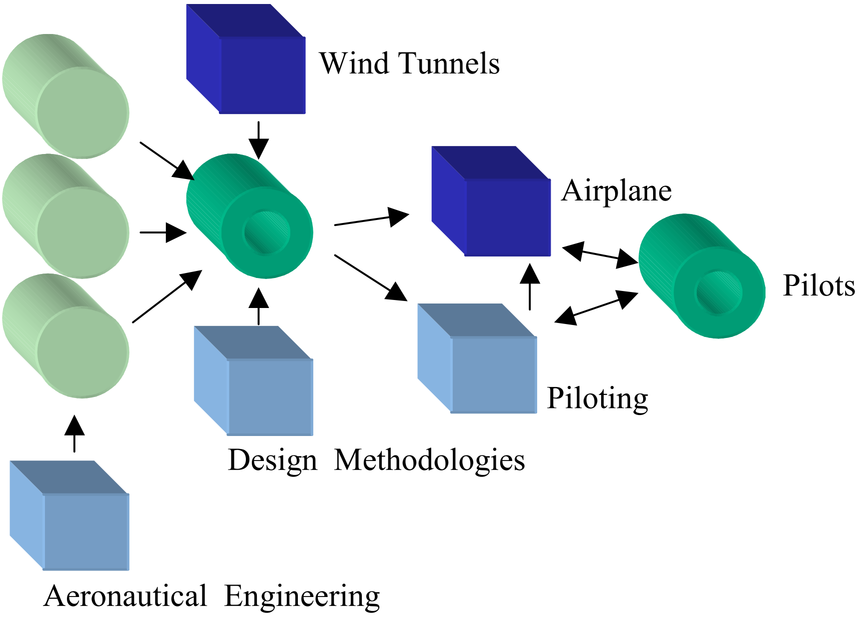
Figure 5.2
Simplified Social Network



Now let's try to figure out how we can integrate these human elements into our former model. Let's use the example of the airplane. In our old model, the development of the airplane would have had a number of technological inputs, including the internal combustion engine, airfoils, and some method for controlling direction. To this we might have added specialized technical knowledge, such as mechanical ability and piloting skills. In our new model, we need to put the humans back into the picture. As a starting point it helps to realize that technological knowledge is usually carried around inside a human's head! So any place we see knowledge, we are likely to see an individual or a group of people. Furthermore, wherever we see an artifact, we are also likely to see a group of people using it.

Figure 5.3 includes our latest ideas. This is not an entire socio-technical network, just a small portion of one. It could be a picture of the development of an airplane at an aircraft company. The company is composed of aeronautical engineers with very specialized technical knowledge. They make use of company wind tunnels as well as design methodologies that are part of this specific company's engineering culture. In designing and building a new airplane, the company is also giving rise to new piloting skills. These skills, along with the artifact itself, define the pilot group. Again, we could choose to make this model fantastically complex, including all the different individuals who work in an aircraft company along with their corresponding technical skills. Our very limited model is sufficient to make a number of important points.

Figure 5.3
A portion of a socio-technical network



One of the first things we should notice is that humans serve as essential linkages between many of the artifacts. When we look at something like an airplane, it appears to be one compact whole. But it only got that way after a great deal of human activity. And the larger network of airlines, airports, air traffic control, etc., only maintains its shape because people are actively holding it together. So we've returned human agency to our model.

But there's another critical point that might be missed. Technologies are not simply additions to the social network; they are fundamental elements. Technologies are not merely social products; they often form the basis of individual identity, social groupings, social interactions, and social actions. Technology is now inseparable from the network. All human societies are socio-technical networks.

Figure 5.4 gives us three different ways for understanding these ideas. In the first line we have an artifact, an individual, and a group. We can imagine these as an airplane, a pilot, and pilots. The artifact defines what these individuals do professionally. While not everyone fits into this sort of situation, we don't have to look far to see that many people in society are professionally defined by technology. In the second line we have an artifact inserted between two individuals. This artifact could be a telephone, e-mail, or perhaps a bus (that transports one individual to another). Technologies knit people together. Imagine what kind of social networks you would have if you did not have use of modern communications and transportation technology? Finally, even if we don't identify ourselves with a particular technology, we often find that artifacts are critical to both the definition of work (e.g. computers in the office) and play (e.g. tennis rackets, football fields). In the end, we must recognize that human society is thoroughly technological. The science fiction portrayal of cyborgs (human/machine combinations) is already here in front of us at a systemic level.

Figure 5.4
Technologies are a fundamental part of society

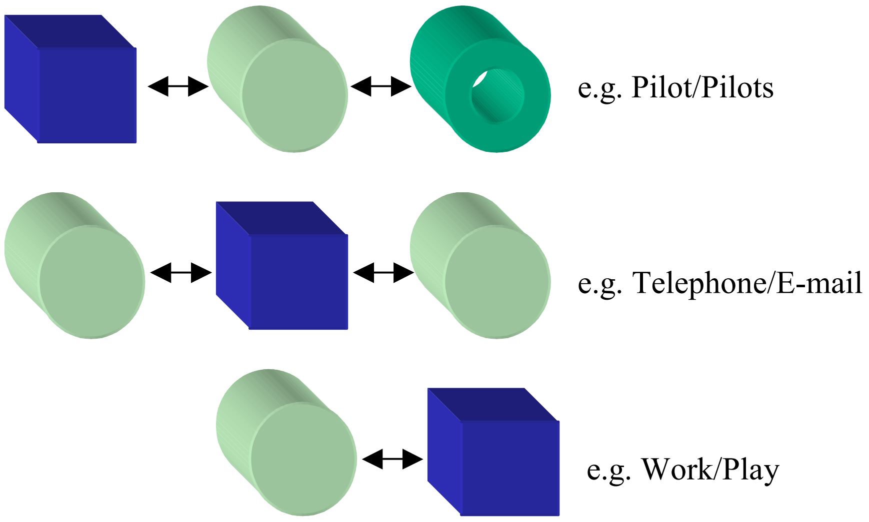
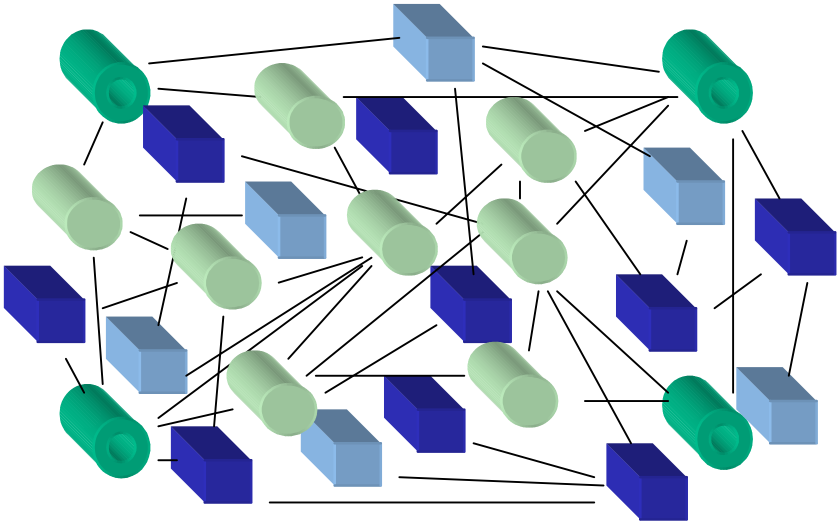


Figure 5.5
The larger socio-technical network



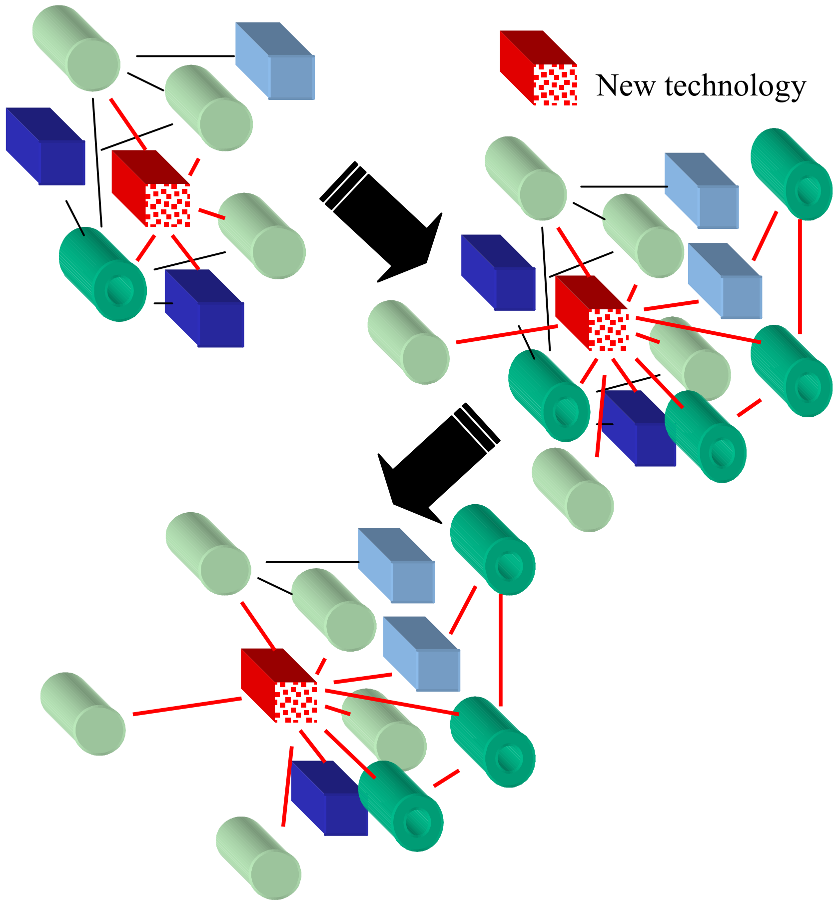
Analysis: Qualities of the Network

While this entire book is essentially about the operation of socio-technical networks, it would be good if we could generalize about change within the network. We'll examine two scenarios: a reactive case to see how the network responds to a new technology, and an active case to show how the network attempts to control the direction of a technology.

In the reactive case we start by imagining an existing socio-technical network. We then insert a new technology, which of course, will come with its own set of artifacts and knowledge. But as we have just seen, technologies also delimit individual identities, group formation, activities, and relationships. The network begins to change, with new relationships forming and old ones disappearing. The new technology may very well displace an old technology and thus force a larger restructuring of the socio-technical network.

The process of adjusting to a new technology is rarely quick and it is often painful. While societies are generally extremely flexible, it often takes years and sometimes decades for the full impact of a technology to be completely felt. Integrating the new technology involves a rebuilding of the network, as it demands new identities, groups, relationships, and activities. The time it takes for a socio-technical network to adjust to a new technology is called *social lag*. Put more succinctly, social lag is the time between the adoption and adaptation. This lag is only generally describable, since technologies and societies undergo constant change. We would be hard pressed to find many situations of perfect socio-technical stasis.

Figure 5.6
Reactive Case

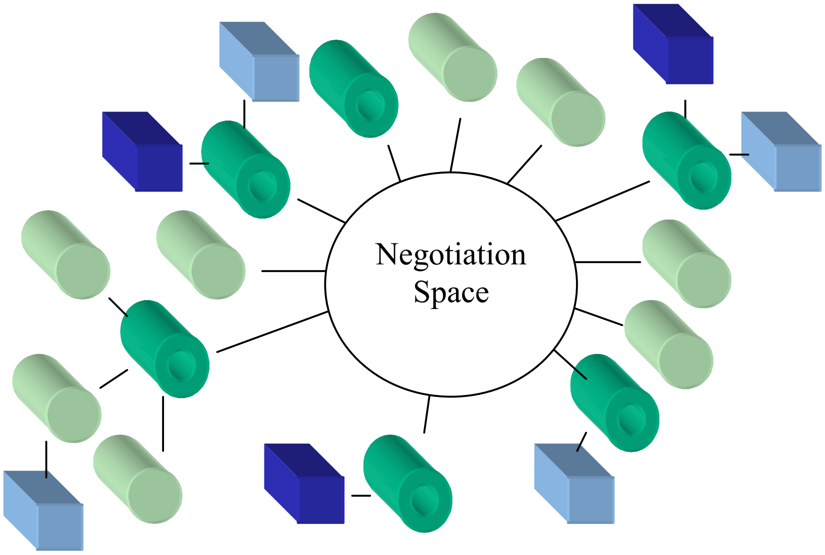


What might be a good example of social lag? We don't need to look far. Consider a company that has been in business for many decades, but only recently began employing computers. We would expect that many of the younger workers, especially those who grew up in the 1980s or later (the beginning of the PC revolution), would have good computer skills. Some of the older workers, say those who grew up in the 1950s or 1960s, might have had little exposure to computers in their life. There are three possibilities for this older group. They might never learn how to use the computers, and thus depend on the younger workers; in this case the company doesn't become fully computer-literate until the older workers retire. The second option is for these workers to learn how to use the computers; this will take a bit of time and money to achieve. And finally, the company may simply decide to fire the older workers. In this last case, the company finds a quick way to adapt to the new technology, but the laid-off workers may never adapt.

The reactive case is very powerful, but its flaws should be obvious. We began by *inserting* a technology into a hypothetical network. We know, however, that technologies do not appear out of thin air. They are products of socio-technical networks. This brings us to our *active case* in which the network defines a new technology.

Crucial to our model is the idea that a single technology is rarely the product of a single-minded effort. Normally a technology involves a large number of individuals and groups. There may be teams of designers spread across numerous different groups. Different people and groups have different goals. They see the technology in different ways and attempt to shape its final form in a way that agrees with their goals.

Figure 5.7
Negotiation Space in our Active Scenario



We call the space in which the technology is formed the *negotiation space*. Here the technology changes shape as different actors vie to impose their own vision. The negotiation space may take place within a single firm. It may be a number of firms jointly producing a product. It could be a collection of firms, public institutions, and consumers. The final form of the product will remain in flux until the actors find some form of workable compromise. When the design of the technology has stabilized, we say that there is *closure*.

Trajectories and Momentum

As an analog to path dependence, we may consider how social factors inhibit the switch to new and preferable technologies. Many times we have the opportunity to change our technology (including the resources), or to make different technological decisions, but we keep using the same technology anyway. In this case we say that there is *technological momentum*.[2] Technologies develop along previously defined trajectories unless and until deflected by some powerful external force or some internal problem. Thus, technologies, because of the socio-technological network, have a momentum (implying that they have a vector -- a direction and a velocity). Don't let the idea of momentum confuse you. The reason the old technology persists is not due to the logic of the technology, it is due to the social agents who persist in using it. There are, for example, some people who refuse to use computers, preferring instead the use of typewriters. We might predict, however, that in a few years a significant disruption to their typewriter supply (including ribbons) will bring this path to an end!

Technological momentum is more interesting when we see it in large-scale technological projects. It is sometimes the case that governments or businesses (or combinations of both) get started on a project that only later appears unwise. Yet once the organizational apparatus is created it is difficult to stop or alter the project. There are simply too many individuals and groups with vested interests.

A More Complete Picture

In our discussion of technological networks in the previous chapter, we saw that artifacts and knowledge formed important limitations in the development of new technologies. This idea led us to the concepts of technological determinism and path dependence. The implication was that technological change followed an ordered and logical trajectory. The technology itself could explain not only future technological developments,

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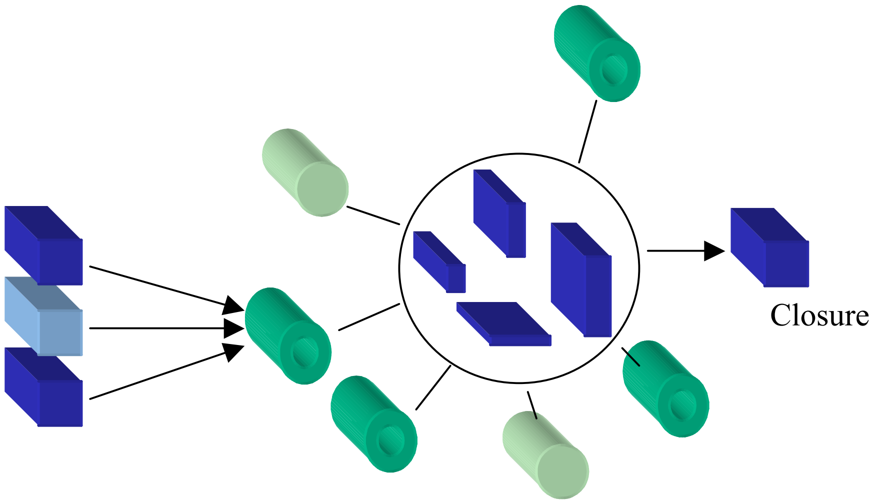
[2] See Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983).

but social change as well. This chapter paints a more complicated picture, with technological change resulting from a social negotiation process. These are obvious analogs to the ideas presented in chapter one: society shaping technology, and technology shaping society. We don't need to view these as diametrically opposed models. There are clearly times when we are at the mercy of technologies around us, and other times when we actively participate in technological decisions, perhaps as designers, perhaps as workers, though more commonly as citizens and consumers.

Figure 5.8
Artifact as Product of Technological and Human Inputs



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6 Invention and Innovation

How do new technologies come into being? Employing the previous two chapters, we would reason that technological creation is constrained by existing technological knowledge and capabilities, but made possible only through human agency. That's a good starting point, but it would be good if we could provide a more detailed model. What this chapter attempts to do is provide a micro-level model for technological change. In fact, it provides a few such models drawing especially from the fields of economics and geography.

It was not long ago that when people imagined new technologies, they thought of great inventors – lone tinkerers who came up with impressive and sometimes strange machines and devices. Inventors still exist, but they have very much been supplanted by the image of the modern invention factory, the industrial research laboratory. In the following reading we will examine two different models for the process of technology creation. How we come to envision this process is crucial for our overall understanding of technology within society.

Our concern is not strictly with invention, but with innovation as well. You might be wondering what the difference is, since these words are often used interchangeably. For our purposes we will take invention to be the first appearance of a new idea. Innovation, on the other hand, is when that idea is developed into a product that can find widespread use. This is not a negligible difference. In developed countries around the world, hundreds of patent applications are filed everyday. Only some of those ideas (inventions) will become successful products (innovations). If you are someone interested in how technology influences economic growth (an economist or politician) than you will want to study both invention and innovation. It is innovation, however, which brings powerful and direct change to an economy.

We can attribute a large percentage of modern economic growth to technology. Whether a country or a company continues to prosper is very much related to its ability to generate new technology, or at least take advantage of another country's new technology. For this reason, countries and companies invest a portion of either taxes or profits in what it called *research and development* (also called R&D). Typically governments fund R&D projects that industry is unwilling or unable to pursue. Businesses usually avoid certain types of research that does not promise much financial reward in the near-term. Or the research might just be too expensive for the private sector to handle.

Traditionally people have used a number of different categories to define R&D. We might divide them into *basic research*, *applied research*, and *development*. Basic research tends to be scientific research that is undirected. That means that the research is not focused on any specific goal, other than to know something about the world. Basic research may also be referred to as *pure research* or *undirected research*. Applied Research is directed research (sometimes called *mission oriented* research). Applied research implies a mix of scientific and engineering activities. Finally, development describes the stage at which an actual innovation (technological product) is created. This stage is usually considered completely outside the realm of science.

The question is, "where do specific innovations come from? How do they come about?" Traditionally people have tried to answer this by asking the following question: is it better to spend money on science (read basic research) or engineering (read applied research or development)?

In the late 1960s, the US Department of Defense funded a study of the development of weapons systems in the US. The project, called *Hindsight*, was to find out whether technologies were coming from basic (undirected) research, or mission oriented research. That is, what form of research gave the Defense Department the greatest return on investment? If the report found any patterns regarding innovations, then these could be utilized in order manage the growth of innovations more efficiently. They looked at twenty weapons systems and divided them into 710 discrete scientific-technological events (when a novel idea occurred that was important to the development of the technology). They found that only 9% of these events or ideas were related to basic scientific knowledge, and that 91% were related to engineering knowledge. And of the science-related events, 97% were motivated by need whereas only 3% came from undirected scientific research.

If you were a scientist, you would be extremely unhappy with the study. This study could be used as an argument that the government should fund less scientific research and more engineering research. The Hindsight study had numerous shortcomings however, the most notable of which was the fact that it only considered scientific research after 1935. Clearly, many technologies of the 1940s, 1950s, and 1960s relied on scientific theories that originated before 1935.

In the wake of Hindsight, two competing studies came out which looked at the development of technologies, and instead of going back only to 1935, considered scientific developments long before then. TRACES, funded by the National Science Foundation, looked at five innovations: magnetic ferrites, the video cassette recorder (VCR), oral contraceptives, the electron microscope, and matrix isolation. TRACES identified 341 research events. This time, 70% were in the undirected research category, 20% were in the mission-oriented category, and 10% were in the development category. They found that 45% of the nondirected research, or 32% of the total research was done 30 years before the innovation. 80% of the nondirected research, or 56% of the total research was done 15 years before the innovation.

The third study, also funded by the National Science Foundation, was called the Battelle study (because if was carried out by the Battelle research institute). In addition to studying magnetic ferrites, oral contraceptives, and the VCR, they looked at heart pacemakers, hybrid grains, xerography, input-output economic analysis, and organophospohoric insecticides. They identified 533 significant events. Here, non-mission oriented research accounted for 34%, mission oriented for 28%, and development 26%. Table 6.1 recaps the results of the different studies.

Table 6.1
Studies on the Sources of Technology

	Hindsight	Traces	Batelle
Non-mission oriented	0.3%	70%	34%
Mission oriented	8.7%	20%	28%
Technological/Development	91%	10%	26%

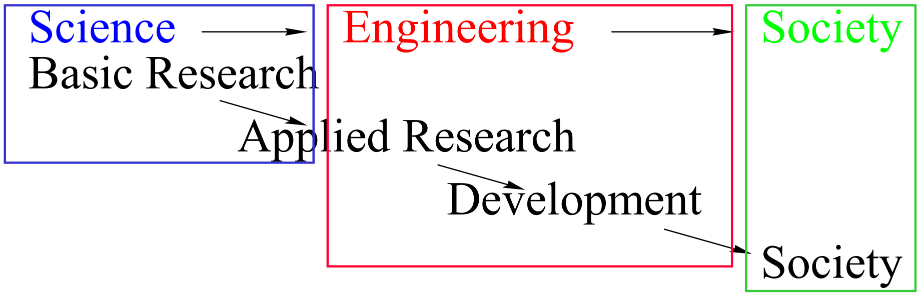
Note: These studies used different categories so comparisons between studies are only approximate.

What is to be learned from these studies? The obvious lesson is that it is very hard to judge where technologies come from. And depending on who does the study, there will probably be bias towards or against scientific research. But one certain lesson is that modern technologies do depend on undirected scientific research, but often that scientific research is quite old. As noted in the TRACES study, 32% of total research was done 35 years before the innovation, and 56% was done 15 years before. Technological innovations don’t necessarily depend on the latest scientific advances. Conversely, scientific knowledge often takes a long time for it to become “useful.”

There are fundamental problems with all of these studies however. They assume a linear model of technological development. That is, they assumed that innovations all begin with scientific knowledge. The terms basic, applied, and development are also weak categories for understanding innovation because they too imply that technological innovations all begin with scientific knowledge.

The linear model (also called the applied science model) is pervasive within science, engineering, business and government. An extraordinarily large number of people believe that this model best explains how we get new technologies. The model has three steps: science establishes theories, engineers apply those theories to arrive at a product, and then the product is bequeathed to society. It appears to be a logical progression from the theoretical to the physical. While it is true that science does contribute theory to engineering, this perspective is extremely limited and unable to explain much technological development.

Figure 6.1
Linear Model of Innovation (Applied Science Model)



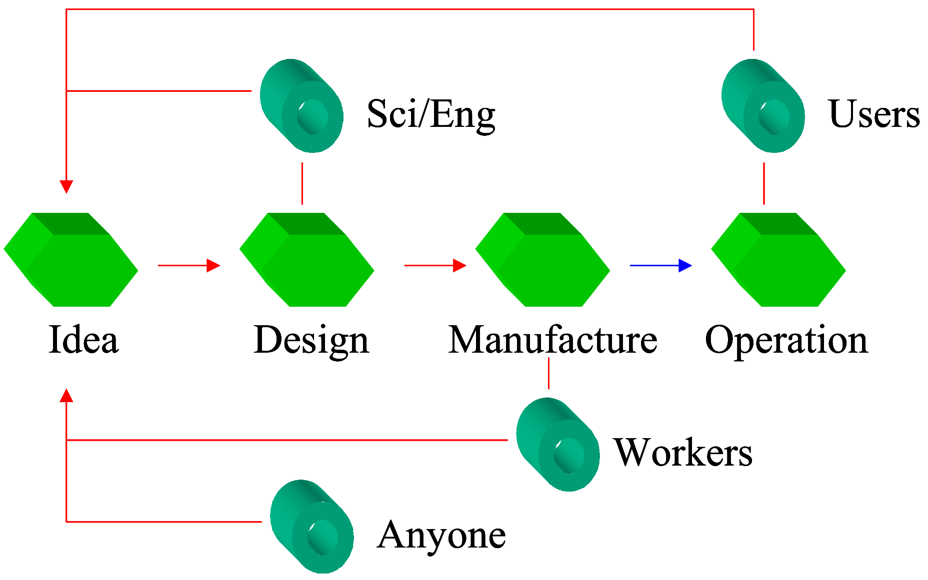
The linear model can be thought of as having two variants: push and pull. Alternatively, we could describe these as supply and demand. The studies above were essentially trying to see what was more important, the supply of new ideas or the demand from the market. The push model asserts that technologies begin with scientific breakthroughs. The pull model asserts that technologies begin with some human need that is met by drawing on an available pool of technological knowledge.

Obviously both the linear push and linear pull models are applicable to a subset of technological innovations. So why not combine them. What is proposed here is a non-linear model. This model begins with the notion that innovative ideas come from a large number of sources. The model establishes very important feedback loops from groups who were traditionally considered downstream of the design process. There is also minimal distinction made between scientists and engineers. Both contribute to the creation of new technological ideas, and neither is considered more important than the other.

Figure 6.2 gives a rough idea of our new model. This is a flexible model, and nothing precludes us from drawing in more links. As it is, however, the model is very powerful, allowing us to take into account ideas that do not come from science (or even engineering). It expands greatly on the crucial functions of engineers, especially design.

There is a linear element to our new model – that is the product life cycle. For simplicity we have placed the disposal stage in the operational stage, and added an idea stage. Were we dealing with a product that did not result in an artifact (some kind of technological knowledge) we would of course remove the manufacturing stage. It is also worth noting that except in one case, all the arrows above indicate the transfer of information. Only between manufacture and operation is there a transfer of an artifact.

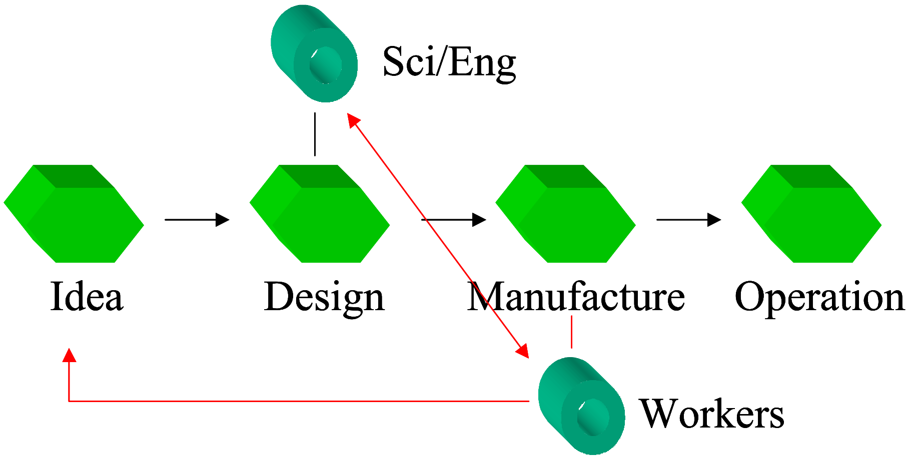
Figure 6.2
Non-Linear Model of Innovation



Thus the non-linear model of innovation recognizes that ideas for inventions can and do come from multiple inputs, and that there are significant feedback loops in the research, design, and manufacturing process. The linear model incorporates no such feedback loops, and assumes that all innovations emanate from a scientific research base. In addition, there is little distinction made between science and engineering. Rather than foolishly asking whether we need to invest more money in science, or more money in engineering, this model concentrates on the actual stages of technological development. Two stages that are very much ignored in the linear model are the manufacturing and operational stages.

A very large proportion of innovations come from the production, or manufacturing, process. We call these *learning-by-doing* innovations, because they were learned while people were trying to make the product (doing). Figure 6.3 illustrates how we might adjust our non-linear model diagram. We draw a new arrow from manufacturing to engineering, as well as a feedback loop from manufacturing to the idea stage.

Figure 6.3
Non-Linear Innovation Model – Learning-by-Doing Variation

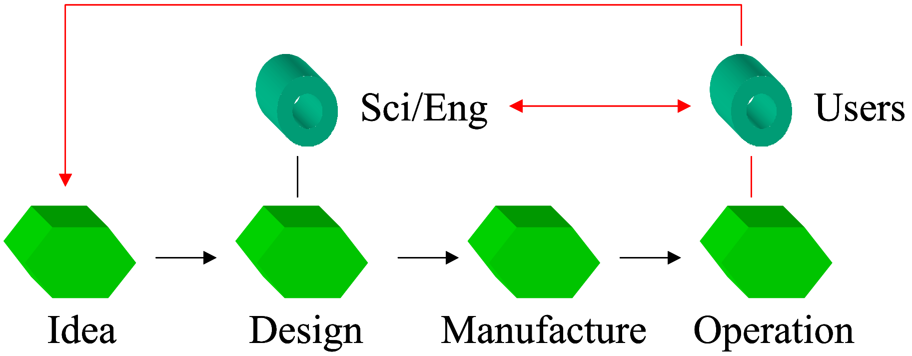


The innovations that occur at this point might relate to the product or the manufacturing process (what economists call process innovations). In either case, we can expect that many of these innovations will be of a small and incremental nature. We would not expect a new revolutionary product to originate from the factory floor (though it could happen).

Managers and engineers often forget about the learning-by-doing process. They sometimes assume that once a product has left the design stage, that it no longer requires improvement. Some of the most important improvements, however, come after the design stage, especially in the manufacturing stage.

In the operational stage we see another important form of innovation, namely *learning-by-using*. Designers often find that in the design and production stages a product's performance is uncertain. Only after prolonged use do they come to understand how products function in the real world. Through learning-by-using, innovations become optimized. Furthermore, it is quite possible that the product will undergo drastic redesign – sometimes becoming an entirely new and original product. We may identify two types of learning-by-using: e*mbodied* (new ideas cause changes in the physical product), and *disembodied* (new ideas cause changes in the use or operation of the product).

Figure 6.4
Non-Linear Innovation Model – Embodied Learning-by-Using Variation



In Figure 6.4 we have added an arrow (a feedback loop) from Operation to Engineering, as well as a feedback loop to the idea stage. At this point the model resumes its functioning as though it were producing a new product. In the end, the new idea is incorporated into a new product.

We see in Figure 6.5 the feedback loop from the operational stage establishes a new idea, but it does not change the actual product. Therefore the change is not manifested in the artifact, but in how it is used.

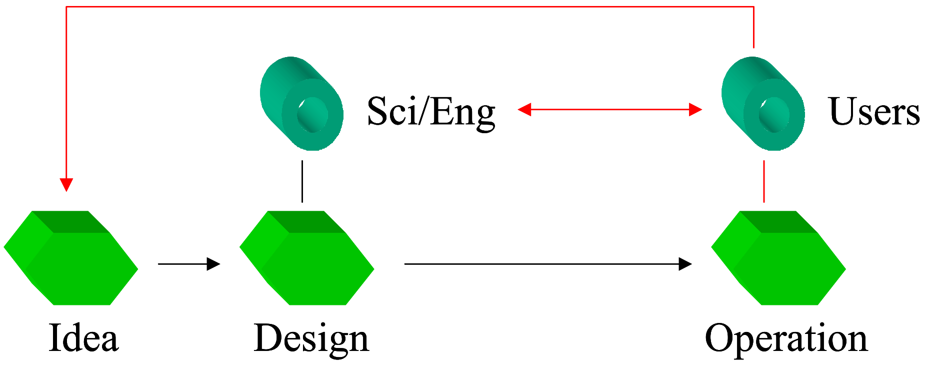
One real world example of this is maintenance costs associated with jet engines. Costs are highest at the introduction of the engine. Through learning-by-using, maintenance procedures become modified, and costs drop significantly.

Another real world example is that of Toyota which makes extensive use of learning-by-doing to improve the quality of its products.

You probably know Toyota for the automobiles they make. But Toyota is also well known for producing high-quality products. Their success is tightly linked to their understanding of the innovation process. They practice what is called total quality control.

Quality control is normally thought of as a way of reducing manufacturing errors. In fact, the type of quality control at Toyota represents a learning-by-doing process. They not only catch defects more readily than other companies, but they come up with new product and process ideas through a learning-by-doing understanding of innovation.

Figure 6.5
Non-Linear Innovation Model – Disembodied Learning-by-Using



At the heart of Toyota's learning-by-doing process is the quality circle. It is a group of workers who share the goal of making the process more efficient, improving the product design, and making the workplace safer. They are trained workers, who understand the entire production process (since they are rotated through the factory and given technical training). They do not just do the same thing over and over again. They are, in a sense, production experts.

In these quality circles, team members isolate problems, rank their importance, and compete with each other to come up with solutions. There is a group leader who presents their findings every few weeks to a larger group of employees, including R&D persons, engineers, and managers. This is the feedback loop so necessary to bringing to light ideas that originate on the factory floor.

Quality circles, production processes, and innovation models are not unique to automobile factories. We can apply these same ideas to many other areas. Total Quality Control, for example, has been applied to the service sector, including banks and hotels and restaurants.

Cluster Models

As we have seen, the non-linear model involves a great deal of information exchange. Indeed, good information flow is clearly a precondition for much of the innovation process. It is also obvious that while inventions might be the product of individual minds, innovations are usually the product of many groups of people. Where there are break-downs or obstacles to the free flow of information we would expect slower rates of innovation. Conversely, where there is an increase in information flow we would expect an increase in innovation.

When we look through the history of technology we see that certain geographic areas have had high rates of innovation. Birmingham and Manchester were important during the British Industrial Revolution. Pittsburgh (US) was the center for steal production in the late 19th, early 20th century. Los Angeles was a main locus for aircraft production at mid-century. Silicon Valley is the current center for computing and the Internet. Information flow is the primary reason for why these centers persist (but not necessarily the reason why they began).

This kind of high-density innovation geography is called a cluster. It depends on the exchange of all kinds of information, including technical, managerial, and market. An economist would say that there is low-cost-of-information in a cluster. A cluster also takes advantage of similar resources, including labor, educational/research institutions, and business support. Ultimately there is a mutually supportive network composed of many firms and institutions that lead to a high rate of innovation.

Conclusions

What is important to realize is that your conception of the innovation process will shape how you organize a company, or even sectors of a society. The linear model of innovation has led companies to isolate their scientific and engineering staff, believing that all the company needed was a consistent flow of new ideas. In the meantime, production languished and these companies failed to deliver high quality products, eventually losing market share to companies that had a more open understanding of the innovation process. Likewise, government emphasis on the linear model leads to a bifurcated educational system, a portion of which serves a scientific and engineering elite, another that produces poorly educated laborers. If you do not believe that workers can have a positive impact on technological innovation, then why spend resources educating them?

One of the main conclusions of the cluster model is that innovation is not merely the product of individuals, laboratories, but of larger, complex socio-technical networks. Innovation is a social phenomenon; it requires that we think beyond scientific research and managerial strategies.

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Part Three

Assembling our World

7 Economics and Technology Policy

The question of government involvement in technology is very much related to the desire to further economic growth. While it is true that governments can pursue technological change for the sake of new technology, this too has vast economic repercussions. Additionally, economists have been instrumental in attempts to understand technological growth, and the ways in which it can be influenced through macroeconomic policies. Thus it makes sense to combine government and economics in the same discussion.

At the risk of oversimplification, there are four ways an economy can grow: investment, commercial expansion, scale effects, and increases in the stock of human knowledge (Table 7.1). The fourth cause, "increases in the stock of human knowledge," is the most interesting to us, since it includes technological change. It is also the area that is of great interest to many businesses and most governments. This is because technological change, by most economists' calculations, accounts for a dominant share of economic growth in the twentieth century.

Table 7.1
Paths to Economic Growth (Mokyr)

Investment	Spending that increases the capital stock, such as tools and machinery, in effect allows workers to produce more goods (an increase in productivity)
Commercial expansion	As the extent of a market increases, productivity can increase because it allows for increased specialization (division of labor) within previously isolated markets.
Scale effects	For the same reason that an expanding market can lead to productivity increases, so too can an expanding population (increased scale). Obviously there is a point at which the size of a population can be a negative influence on productivity.
Increases in stock of human knowledge	This includes technological change, as well as organizational and institutional change.

Just how does technology provide so much to economic growth? There are two ways we can think about this. First, technology helps us do things more efficiently. So for a given amount of capital and labor, new technology may help us produce more (or likewise, produce the same amount with few capital or labor inputs). Technologies used in this fashion to reduce inputs are thus either capital-saving or labor-saving. Second, and more important, technology permits us to do things that we could never have done before, even if we had a limitless supply of capital and labor. This latter effect is a qualitative change that is very difficult to measure in relation to earlier technologies. To give an example, the achievements of commercial aircraft transport could never have been matched by previous technologies (railroads and ships), even if we had limitless capital and labor to put into the former technologies.

Realizing that technological change is important to economic growth, we are faced with the issue of what role governments play. Can governments influence technological change? If so, how? What is the influence or result of specific policy actions? Are all economies influenced in the same way (e.g. a developed economy versus a developing economy)?

We may begin with the question of whether governments should get involved in technological change in the first place. Why can't technology be left entirely to businesses? Firms, after all, are the ones that must show a profit at the end of the day – won't they make the best decisions about which technologies to pursue? This question is misleading, however, since nearly all governments are already involved in technological change (as will become clear below). The question is not whether they ought to be involved, but how, and to what extent. Furthermore, while it is true that businesses are usually better than governments about making business-oriented decisions, businesses can be terribly shortsighted in the development of technology. Existing firms and business patterns often tend to reinforce existing technologies. As we will see, government technology policy can encourage the development of new areas of technology that businesses might have ignored.

Technology Policy

Inevitably, governments have technology policies, even when there is no stated "technology policy." We may divide these policies into passive and active measures. Passive measures include laws and regulations. By themselves, these tend to exert an indirect and limited involvement in technology decisions or market decisions related to technology. Table 7.2 gives a detailed listing of different legal or regulatory measures.

Passive measures provide a framework in which the market can act out its own technological direction. We might make an analogy to a basketball game. Passive measures would include establishing the rules of the game and providing the referees, but certainly not training players or becoming involved in the play of the game. This does not mean that passive measures are weak or unimportant; in fact they can be extremely powerful in shaping technology.

Most governments also have active or interventionist policies. In our basketball analogy, the government may not only train and coach the players, but may become one or more of the players on the court. Among the different options available are: education, research, procurement, and promotion (see table 7.3).

Table 7.2
Passive Technology Policy Measures

Intellectual Property Rights	Provides incentives for the creation of new knowledge, including technology, by granting exclusive ownership (a legal monopoly) for a period of time.
Standards & Codes	Some governmental standards protect safety (e.g. building codes) while others protect the environment.
Market Reforms	Governments establish regulatory structures that permit the operation of capital markets (banks and stock exchanges). Capital markets influence the investment in new technologies and the creation of new technology ventures.
Trade Policies	Governments can protect local industries through tariffs on incoming services and goods, and go so far as to prohibit specific foreign items.
Tax Policies	Like intellectual property rights, tax policies can be used as incentives to encourage the development of, or investment in, new technology.

Education appears innocuous as a policy, until we realize that it is the mechanism by which the future labor force is trained. Any educational system must be matched with the expected needs of the future economy. The government can heavily influence the labor force, and bias an economy's technological direction by adjusting its investment in different types of education (e.g. vocational versus general education) as well as emphasizing specific areas of higher education (e.g. computer science over aeronautics). There is no question, education policy is the cornerstone of any technology policy. Despite pronouncements to the contrary, governments often overlook it because there is a long lead-time before educational investments pay off.

Governments perform research for two broad reasons. First, they require some research for their own operation or the public good (e.g. land mapping or health research). Second, and more importantly, they do research in areas that businesses do not. Businesses often avoid research that is costly (the equipment may be too expensive) or does not promise a return on investment quickly enough. For this latter reason, much government research has gone towards long-term basic research, where the results are of a more generic (non-applied) nature.

Table 7.3
Active Technology Policy Measures

Education	This includes all forms of government sponsored education. University and vocational training usually have special roles within technology policy.
Research	Governments often carry out some scientific and technological research in their own laboratories (e.g. health and environment). They also fund research at private firms and university laboratories.
Procurement	Government purchasing. This ranges from the mundane (paper clips) to the monumental (nuclear weapons for national defense).
Promotion	Market intervention that attempts to develop a specific technological area, or produce a specific product.

Procurement simply means buying. Governments buy things for their own operation as well as the smooth operation of the economy (e.g. infrastructure). Here, governments may influence the technological direction by purchasing specific technologies, or favoring specific firms over others. More importantly, governments often buy things that are at the leading edge of technological practice. For centuries, perhaps millennia, the most important area in this category has been military technology. Not only have military needs pushed the boundaries of technology, they often result in commercial applications of the same or similar technology. This is a phenomenon called *spin-off* or *spillover*.

Finally, there is promotion, in which governments become active players in the market. Promotion involves the highest amount of risk because it requires governments to make long-term business decisions. At a minimum, promotion involves choosing a particular area of technology that the government believes will be economically significant. Riskier still is when the government pushes specific products, perhaps developing them at government owned (wholly or partially) firms. The problem, as should be obvious, is that governments are not businesses, and do not make decisions strictly on the economic merits of a project.

Development Policy

Between "developed" countries such as the United States and developing countries such as Malaysia, there is a great difference in technology policy. The US economy does not require strong direction from the government in choosing which technological paths to follow. Businesses, for the most part, have sufficient innovation strategies in place, as well as the resources (labor and capital) to pursue such strategies. Innovation in developed countries is, in a sense, self-starting. This is not to say that governments in developed countries are not important to the process of technological change (far from it), merely that businesses provide much of their own leadership when it comes to commercial development. Developing countries face much greater obstacles. Companies not only do not have the latest technology (or the staff to use it) but often do not have any technology strategy.

In the mid-20th century, economists and government leaders had a very naïve view of development, and what it would take for a country to modernize and industrialize. Modernization and industrialization were, of course, not ends in of themselves, but means to grow an economy and improve living conditions. Development was seen as a simple matter of getting developing countries to use the technology of the developed countries. It sounded easy, but it wasn't.

The movement of technology is indeed one of the principle objects of development policy, but it is a complex process. Technologies move from place to place all the time. When it occurs in a largely unplanned and informal manner, we call it *diffusion*. When it occurs as part of a formal attempt to move it from point A to point B, this is *technology transfer*. The problem is that you can't simply put a piece of technology on a ship, move it to another location, and expect it to work (much less cause an industrial revolution!). Technologies require people to operate them. They require services that can fix them, and supply raw materials. They require institutions that can finance them, and, more importantly, provide markets for the finished product. The naïveté of the mid-century economists and government planners was in not realizing that technologies are embedded within existing socio-economic frameworks. Pulling the technology out of one framework and dropping it into another will not necessarily recreate the successful economic framework of the first. At a deeper level, these planners also did not realize the degree to which many technologies are culturally weighted. Technology transfer might fail for no other reason than the receiving country's values and belief systems.

More recently we have begun paying more attention to the conditions surrounding successful and unsuccessful technology transfer. At the heart of the process is the technological capability of individual firms within the developing country. We may generalize about four different types of capability (table 7.4).

While it is true that all countries experience unique paths to industrialization, it is not uncommon for firms in developing countries to proceed through the four types as if they were stages. There are good economic reasons to do so, not the least of which is that it is unnecessarily expensive to reinvent technologies already developed elsewhere. Adoption, in contrast, requires the least amount of investment in equipment and human capital. As workers adopt the newer technology, they become more familiar with it, and eventually learn to change it to suit their needs. Finally, as firms realize the competitive importance of innovation, they build into their organizations the capability for continuous technological change (e.g. investment in long term technological research).

Table 7.4
Four Types of Technological Capability

Isolation	A firm that lacks the ability to develop its own technology and is unable to adopt outside technology. It is effectively locked-in to a specific type of technology.
Adoption	A firm that has the ability to use advanced technology from elsewhere.
Adaptation	A firm that is able to adapt (perhaps redesign) advanced technology from elsewhere for local conditions or markets.
Indigenous Innovation	A firm that has the capability to design and produce advanced technology.

It is not the case, however, that a firm must proceed through the different capabilities in a step-wise fashion. In some cases, it may even be unwise to do so. For example, a firm that merely adopts technology from elsewhere may be using technology that is no longer competitive (especially by the time the firm has it operating). Nor does purchasing existing technology necessarily increase the capabilities of a firm's workforce. In some cases, if a firm is investing in fixed and human capital anyway, it might attempt to go straight to building some sort of innovation capability into the firm.

Firm Capabilities

Within firms, we may consider four different areas of capability: management strategy, human capital, physical capital, and access to technological information. Management strategy is the least tangible of all these categories, since it refers to the organizational capabilities of a firm. Does the firm have both the realization that technological innovation is a competitive advantage, and a plan for executing technological change? Firms that lack such strategies present a sizeable obstacle to overall technological growth within an economy; oftentimes such firms only begin to build-in strategy after they have suffered significant losses to competitors that have advanced technologically (at which time it may be too late).

Human capital represents a firm's skill base, such as the number of engineers, scientists, technicians, and workers. Without the proper skills, companies are unable to adopt outside technology, much less create their own. As firms have increasingly higher proportions of advanced technology, and as they move to develop new technologies in-house, the demands on human capital increase. Physical capital represents necessary machinery and equipment. Some of this equipment may embody advanced technology. For developing countries it is often the case that this equipment must be imported from developed countries. Finally, firms depend on access to advanced technological information. This can come from a number of sources including: local universities, scientific and engineering publications, espionage, and the transfer of personnel.

Figure 7.1
Firm Capabilities

All too often government planners become distracted by the physical trappings of technology (e.g. a new laboratory, computers in classrooms, a high technology park) without realizing that innovation is more than just high-tech gadgetry. By focusing on firm capability, technology policy can directly address the needs of an economy. As mentioned previously, governments are in a bind when firms themselves are not oriented towards innovative strategies. In this case governments may enter into commercial technological investments on their own (promotion), or establish business incentives that effectively convert local firms to adopt new technology.

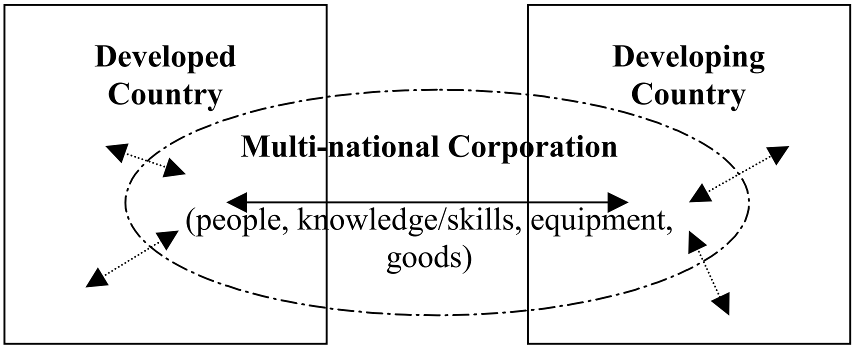
In most cases, the largest government investment must go to the development of human capital -- not merely the training of a small scientific and engineering elite. A developed economy needs a population with a relatively high general level of skills. A good example of this is the construction industry in developing countries. Highly educated engineers may design a fantastically advanced skyscraper using the latest building technology, but all this is useless if the workers on the construction site lack training in the latest methods. In such cases, advanced technology remains stuck in the laboratory and on the drawing boards.

Physical capital represents one of the more tractable problems. Buying equipment and machinery may be expensive, but it does not require the same long-term investment that education does. Indeed, the greatest obstacles of new equipment is often finding people who can use it properly -- a human capital problem.

Finally, regardless of whether a firm is using technology developed elsewhere, or creating its own, it always needs access to outside technological information. To this end governments establish research universities and research institutes. While these organizations come up with their own innovations, they also serve to connect local businesses with best-practice technology. In many cases this connection between firms and research centers is a function of personnel exchange (again, a human capital issue).

One of the fastest ways for governments to transfer technology is through what is called *foreign direct investment* (FDI). A typical case of FDI is when a multinational corporation establishes a manufacturing plant in a developing country (where labor is typically less expensive). Obviously this kind of investment and technology transfer may help an economy, but such low-cost manufacturing operations are better at employing people than they are helping an economy establish technological capability. FDI is more useful when the operation shifts to more capital-intensive technology that requires more skilled labor and higher quality service and material suppliers. A semiconductor factory is thus more beneficial than a shoe factory since the former will require training more people to a higher level of technical proficiency, as well as improve the subcontractor and supplier networks which provide materials and services. The best kind of FDI occurs when the company establishes true research capabilities in the developing country and attempts to use primarily local labor and local suppliers. Governments can place restrictions on FDI in order to encourage such local capability growth.

Figure 7.2
Foreign Direct Investment



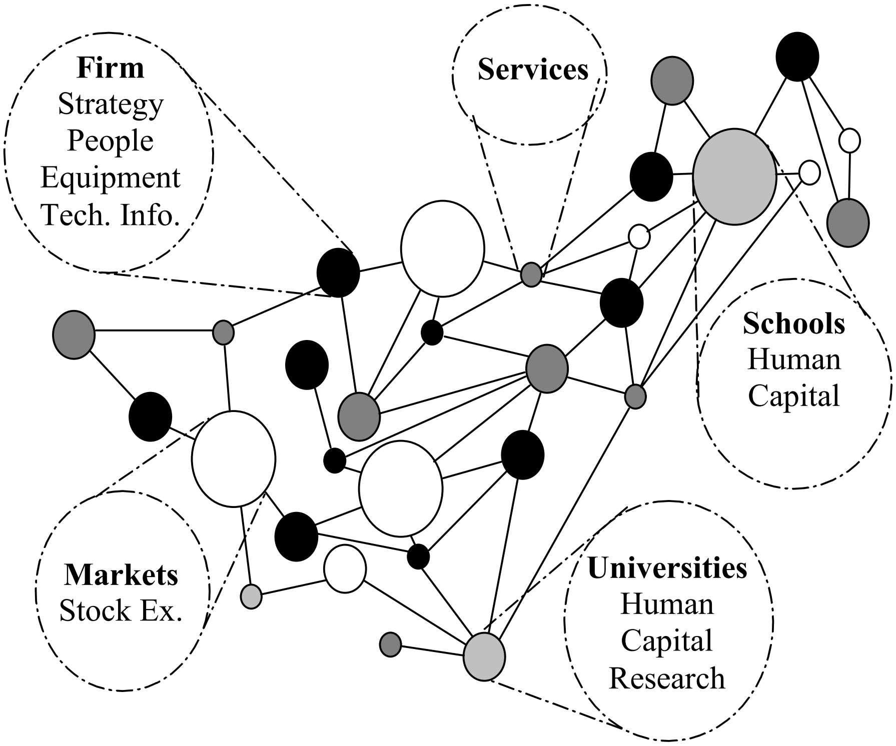
Firm Environment

A thriving economy is not simply an agglomeration of individual firms. They exist within institutional and market frameworks that deeply influence technological capabilities. They are tied to these frameworks through formal and informal links, which taken as a whole constitute an innovative unit that is greater than the sum of the parts. That innovation is a quality of a network of companies and institutions within a common market (and usually a common geography) is a subtle idea, and one only recently recognized in the field of technology policy.

Among technology firms, we hope to find both large and small corporations. Large corporations bring with them many organizational capabilities, and typically have strong commitments to research and development. We might expect large firms to crowd out small firms over time, but this has not been the case. Small firms are often more agile in moving to new technologies, and small firms provide entrepreneurs larger financial rewards than might be possible within large corporations.

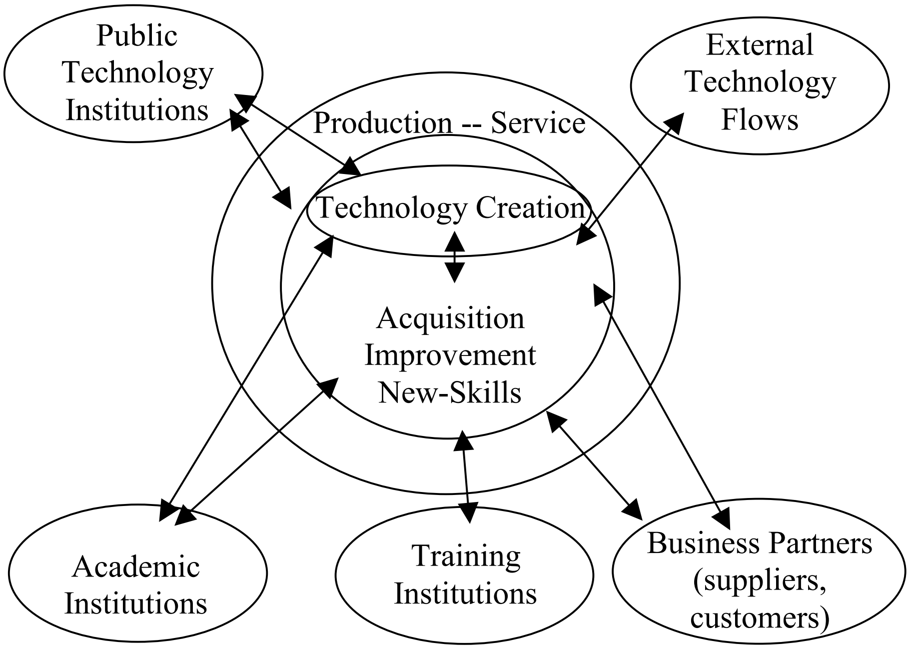
The private elements of the innovation network extend well beyond the traditional technology firm. They include a multitude of firms that provide essential services including legal assistance, financing (especially venture capital), and marketing/distribution. These services are of special importance to small firms and start-ups that lack many of the organizational capabilities of large multi-national firms. Stock exchanges are also important in providing capital to growing companies, as well as exit opportunities for venture capitalists.

Figure 7.3
The Firm Environment



On the public side, there are schools (primary, secondary, and tertiary) providing human capital and research. There are government funded laboratories, as well as government funded research within the private sector. The government, as noted elsewhere, provides much of the basic economic infrastructure (roads, water) as well as regulatory and legal frameworks.

Figure 7.4
Firm Innovation Resources (courtesy of Greg Felker)



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8 Defining the Environment

When people talk about technology and the environment, the discussion is usually framed in terms of technology's impact on the natural world. For example, we constantly hear about automobiles causing air pollution. We hear of agricultural production consuming forests and jungles. And we hear of factories polluting rivers with toxic effluents. But the way that technology is blamed for the environment's ills should strike us as simplistic.

A technology that pollutes is not an accident; it is a tangible expression that, as a society, we value the fruits of the technology over a pristine environment. The technologies that impinge on the environment reflect society wide decisions about what we value most. Clean air is simply not one of them. I say "as a society" because for many of us, we did not have any decision making power over technologies that came before us. To say all of this, however, is merely to reiterate our theme of technology as social construct.

Alternatively, the case of environmental degradation gives us a stark example of the degree to which we feel powerless in the face of technological change. Who among us really wants dirty air or dirty water? Is there a radical anti-environmental lobby out there that wants an end to all wild elephants? It would appear to be a case of technology out of control – technology taking us down ecological roads we do not wish to venture. In short: technological determinism. If technology were completely a social construct, we would have eliminated pollution very quickly.

The ecological choices we face today nicely illustrate how social construction and technological determinism operate simultaneously. We do get to make choices, but our range of options is not infinite. Over the long term, our options include only those actions that are physically possible. Over the short-term, our choices are limited to a much smaller set of known options. In the end, we realize that technology doesn't give us everything we want, but of the technological options available to us, we have chosen a very specific set of tradeoffs that mirror our values and power structures.

There is a deeper argument to be made, however, and it concerns the relationship between technology and nature. We began this book offering one definition of technology that juxtaposed the human-made with the natural. A rock chosen by a hunter and used to kill an animal becomes a weapon, a technology. More generally, humans need not change the fundamental shape of nature in order to frame it as a technology. We merely need to define it, control it, and use it for our purposes. In our modern world, nature has become, for the most part an indistinguishable part of our global technological system.

Our Unnatural History

Human destruction of the environment goes back at least as far as the Neolithic revolution when humans began to carve out settled ways of life. Intuitively, we understand that this was environmental destruction at a very limited scale – nothing like our own. But there are fundamental similarities. Neolithic peoples began farming and building settlements, began modifying the environment because they sought (we presume) a stable food supply and shelter from the vagaries of nature. It was probably not evident at the time that this choice involved a new relationship with nature, that people were trading a pristine environment for health and material safety. But it is now.

We continue, despite the fantastic material wealth of the developed world, to be a planet in which most inhabitants are making a simple choice in favor of a little more food and a little better shelter. The fundamental difference between today and 10,000 years ago is the planet's ability to absorb our modifications. By every indicator, nature is becoming unable to bounce back. We risk not only a small plot of land and a little village site but the entire planet. The irony is that the economic systems upon which we rely for food and home require the consumption of our natural environment. It may not be too long before the failure of the environment becomes our economic undoing.

Moving beyond haphazard meddling with the environment at the start of the Neolithic, when did we begin to throw our environment out of balance? Interestingly, devastating environmental problems existed quite some time ago. The deforestation of Greece and Italy took place well before the modern age. Many locations in the two countries not only have few trees, but also little topsoil. In many locations, only a scarred rocky surface remains. Deforestation, over-farming, as well as the occasional extinction of an animal species due to hunting, these were all to be found in pre-modern human history.

But when things really got moving was the industrial revolution. It combined certain exploitative and polluting activities with fundamental changes to society. There was increased resource use, increased urbanization, increased population, as well as increases in air and water pollution. For all of this, the industrialized world began to eat better, live longer, and become wealthier. For all the ills that our technology seems to carry with it, very few people are clamouring to return to pre-industrial modes of technology (there are some). If it turns out that we are able to find a solution to our impending ecological disasters, then industrialization might well be regarded as the most important development in the improvement of human welfare.

Public Outcry and the Redefinition of Nature

You might guess that public outrage over the loss of natural environments is a recent social movement. But people began to worry about nature in the early years of the industrial revolution. Nature and pollution were part of a larger concern about how industrialization was distorting man's relationship to each other and to the world. Factories seemed to be tearing apart the human bonds of family and village, replacing daily and seasonal rhythms with unyielding mechanistic efficiency, and fouling the skies and waters.

As a response, poets, writers and artists in 18th and 19th century Europe began extolling the idea of nature, pristine and unspoiled by the hands of man. For these people, nature was not merely a place in the woods or a mountain view, it was idealized as a kind of spiritual and moral purity. The loss of nature spelled the downfall of man, a kind of second expulsion from the Garden of Eden.

Many people still hold a view similar to this, that nature represents a kind of purity and that through it humans can find deeper meaning and spiritual calm. It is restorative of both mind and body. As a corollary to this, technology and industry took on a dirty connotation, tainted and impure because it was the work of humans.

Towards the end of the 19th and the beginning of the 20th centuries, new attitudes towards nature emerged. Nature was not merely held in juxtaposition to the man-made, it became a resource to be preserved, conserved, and utilized. Nature, even in its pristine, untouched state, became framed in terms of its utility to man’s larger technological enterprise. This utility functioned on at least two levels: nature had valuable resources that could be exploited; and it had natural beauty which, becoming increasingly rare and under threat from humans, needed to be protected so that humans could retain a link to our pastoral origins. This was especially important at a time of increasing alienation arising from anonymous urban living and dehumanising factory work. Many people continue to maintain these views of nature as well as the earlier romantic views.

One of the practical outcomes of the conservation movement was the creation of ecological preserves, tracks of land and bodies of water that were off-limits to development. Another strand of conservationist thinking led to the damming of rivers in order to exploit their electricity generating potential, and reroute the water for farms and urban oases. Nature was to be preserved, managed, and exploited.

In mid-century (the 1950s to 1970s) the green movement, as we know it today, took root and quickly grew. People perceived technology as out of control and destructive to both nature and humanity. Some of the early green efforts had a "turn back the clock" philosophy, that the only way forward was to return to earlier forms of living. In the 1960s, at the height of the hippie movement, some took this very seriously. And as is characteristic of all the environmental paradigms that I've discussed, the green movement was part of a larger contemporary political movement. The green movement's ideology meshed with the anti-war, anti-nuclear groups of the day.

The age of the green movement saw the development of governmental regulatory structures, such as environmental protection laws and agencies. Nature could not simply be walled off, it had to have active protection. The political awakening to environmental problems was very much influenced by frightening reports on the devastation caused by industrial chemicals. In the US, dioxins and DDT became rallying points for trying to reign in all industrial pollution. Dioxin, a toxic chemical manufacturing by-product, was turning up in groundwater and eventually polluting drinking supplies. DDT, a highly effective chemical for mosquito control, ended up in the animal food chain to devastating effect. Other countries had similar disasters awaken their environmental consciousness. In Japan, the major disaster was the Minamata Bay mercury poisonings caused by a chemical company that dumped an estimated 27 tons of mercury into the water. The mercury eventually made it into human diets. These cases resulted in public alarm, and since these chemicals were largely invisible, people began to wonder what else we might be doing to the environment and thus to ourselves. Protecting the environment wasn't merely a spiritual or economic proposition, it came to be directly associated with human well-being. It is from this particular political climate that academia began to take a stronger interest in environmental and technological matters. The environmental sciences, science and technology policy studies, as well as technology and society studies find part of their intellectual heritage in these movements.

The post-regulatory environment has moved in a number of different directions. One response has been a backlash, mainly from corporations that stand to lose from environmental regulations. They typically argue that the green groups use "trash science" to support ideological rather than rational viewpoints. Another response has been to move beyond regulation, beyond creating eco-police, to thinking about how we can have both economic development (which puts food on people's tables) *and* some amount of environmental balance. This is called the sustainable development movement. It has two major premises: that we need to plan for the long-term, and that we need to decide on just what kind of environment we want. Finally, a third response has been to treat environmental problems as revolutionary causes. These are typically fringe groups advocating eco-terrorism, but despite their sparse numbers, their activities generate a great deal of media attention (e.g., bombings, tree-spiking, bull-dozer wrecking). The eco-revolutionary movement is notable because it turns against the longstanding philosophical, religious and intellectual argument that humans stand over nature.

The most recent developments in our framing of nature are to view it in terms of a large-scale political and economic struggle. Developed nations have the highest per-capita pollution, but reap the benefits of the cleanest air and water on top of very substantial material wealth. The world's poor suffer in conditions of the highest pollution and environmental destruction, yet they benefit the least. The ability to export one's problems has a catchy name: NIMBY, or Not In My BackYard. It is our ability to segregate the benefits of a technology from its liabilities that allows the wealthy to ignore environmental problems. We end up in a situation of environmental haves and have nots, though problems like global warming promise to be less discriminating.

Resolution

The different visions of nature and the environment do represent shifting paradigms, but there is real progress. It is significant that we now have a better understanding (though far from complete) of the complexity of the relationship between human society and nature. And the more recent movements have also got it right, that these questions go to the heart of our economic systems and our methods of technological governance.

Politically, the question is whether the will exists to form the necessary consensus to take action. Environmental decisions have traditionally been beset by free-rider problems. Companies typically are not going to act in the best interest of the environment if it is a cost they assume and their competitors do not. Similarly, countries are not going to commit to environmental action that they feel unfairly penalizes their economic competitiveness. This is very much the debate that is going on right now among developed and developing nations. Most countries do believe that something needs to be done, but they haven't figured out a way to do it to everyone's satisfaction.

Economically, the question is whether we have enough surplus (food, energy, etc.) to absorb the cost of clean air and water, and protected habitats, without impairing the functioning of our economic system. That is, can we afford it? We will no doubt find some technological solutions, but our answers may well be organizational and social. That is, we may find that alternative economic, legal, or lifestyle arrangements are able to do for us what the machines cannot. If we don't, then our economic health may be doomed anyway.

Another difficult challenge is the role of science and scientific knowledge. Part of the problem in forming consensus is figuring out whether there is a problem in the first place, and then deciding what actions need to be taken. It is often the case that even when a significant number of scientists express alarm on a particular issue, nothing is done until the trouble is already upon us.

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9 Security

This chapter is about the role of technology in defining security. It is about how we use technology to prevent harm from others, whether we are talking about someone trying to harm us, or someone trying to take our material goods upon which our health and happiness depend. It is also about how technology is employed to destroy, or disassemble these techno-security systems.

It may be obvious to most people that technology is an important determinant of security. What may not be so obvious is the degree to which these systems wrap around us at the local level, and circumscribe relations at the regional (e.g. international) level. From a historical perspective, the technology of security has provided one of the strongest inducements to innovation, or at least certain types of innovation. In this way it has had a strong shaping effect on the rate and direction of technological change.

The second broad thematic point of this chapter is to explore what lessons we may learn from this relationship between technology and security. Simply pointing out that techno-security systems exists deprives us of some fascinating and perhaps troubling insights into human society. How is it that much of our technological creativity revolves around the destruction of human life and property? And what do we learn about the nature of technology and its potential to maintain or disrupt local and regional security?

Meaning and History

Let's start with the idea of security. Of course we are thinking about how we keep ourselves safe as well as protect the material means that keep us fed, housed, and happy. But there is more to this idea. That we must think about security speaks volumes about the human condition, about our failings as individuals and groups. Most societies, with mixed success, have established cultural, organizational and technological means that attempt to maintain security. Every society contains a number of individuals who are unwilling or incapable of acting in a civil manner, of respecting even the most basic norms (e.g. not killing one another). Thus, one version of security is about establishing social and technical mechanisms that balance these destructive individuals and groups. As we proceed, however, we will see that security relationships are much more complex, and that civil societies also attempt to create security imbalances. Let's take a brief examination of the evolution of security and technology.

We've already discussed some early security technology in earlier chapters, including Neolithic homes. As a simple way of keeping raiders out of the home, villages would create a structure without external doors. To enter, one had to use a ladder, which was pulled in at the end of the day. Of course going up and down a ladder can be immensely inconvenient, especially if you are infirm or carrying goods. The answer is a door, but too many doors or poorly constructed openings create too many opportunities for thieves. So, in structures the world round, humans have established secure dwellings that minimize external openings and place bandits at a disadvantage. A widely utilized tactic has been the multi-level home, with one large door and no large windows on the ground floor. The occupants slept on the upper floors with their modest valuables, thus providing a tactical advantage. Another similar tactic involved layering a home's defenses by placing the sleeping quarters and valuables on an inner layer.

Castles, which guarded royalty and wealth employed many such defensive features. In addition to high walls and the occasional moat, castle builders used many smaller and less obvious designs. The entranceway, for example, was off set from the gate; attackers thus had to make a turn when rushing the main compound. Japanese designers employed a feature known as "nightingale floors"; they were intentionally creaky (sounding like birds chirping), thus thwarting any assassin's attempt to sneak about by stealth.

One of the most effective personal security technologies humans have developed, and one of the least expensive, was the domesticated dog. While not a material technology like a hammer, the dog is nevertheless a long way from its wild cousins. Over many centuries, humans have developed breeds for many different tasks, among the most important being protection of the master. It is not by accident that dogs form strong bonds with their owners, and will bark, growl and bite threatening strangers. These are traits humans have sought from canines over thousands of generations; the result is an animal that is loyal and highly effective at protection.

Security concerns are still with us. If we examine our homes, our places of work, we'll find that we employ security technologies a few times a day. We place key locks, dead bolts, chains and peep holes on our doors. We employ door codes, electronic alarms, motion detectors, window bars, and security cameras. We still have walls, but have created modern interpretations in the form of chain-link fencing and barbed wire. In stores and libraries, we frequently tag items with magnetic strips, and leave magnetic detectors to guard the exits. And if we take an airplane flight, we walk through metal detectors and have our luggage x-rayed.

These kinds of defensive techniques are only part of the history of security. They are tightly intertwined with the history of weapons, which humans presumably developed for hunting, protection, and raiding. Indeed, if we consider something like an early stone axe, it is easy to imagine that humans (or their ancestors) would have fairly quickly realized a multiplicity of uses for such implements. And regardless of whether the first use was offensive or defensive, we understand how the two opposing sides of a conflict would have sought to "rebalance" the tactical situation by developing better weaponry and better defenses.

City and State

When it comes to security, however, the best way to truly gain a significant advantage is to group with other people. Safety in numbers is self-evident. Family compounds, villages, and eventually cities made it more likely that a single family would survive. This is not to say that cities are without criminal behavior, but they are particularly resistant to attack in a way that an isolated dwelling is not. Indeed, as cities grew larger, they gave rise to their own brand of mischief. For now, however, it is important to see the link between social groupings and defensive systems. While we probably understand that pre-industrial urban centers grew due to increases in trade, they were equally important as safe-harbors for the people and activities within their bounds. Many cities around the world built walls for safety. The great trading city of the Adriatic, Venice, grew successful in part because of its protected location on the islands of a lagoon. The protection afforded by size gave impetus for the creation of trading leagues as well as more centralized states and empires.

As was pointed out in a previous chapter, the rise of cities was part and parcel of economic growth. And with a large enough economy, individuals could specialize in a particular trade. This was as true of security as it was of the crafts. Cities could create and maintain their own force to maintain order. So instead of every citizen having to tend to their own protection, cities created organizational means for placing the task in the hands of experts. The police, as we call them today, employ their own technological means to establish the tactical edge over criminals: guns, batons, pepper spray, bullet-proof vests, helmets, riot shields, surveillance cameras, radios, listening devices, helicopters, etc.

As cities and trade grew, it became possible to devote ever-greater amounts of wealth and labor to the problem and opportunities posed by security. On the one hand, cities (and later states) could raise and supply armies for the defense of a region. On the other hand, the same armies could expand a city or state's territory or wealth by attacking others. It should be noted that it is not the case that cities and states were necessary conditions for the development of armies; as I wrote in chapter two, nomadic cultures gave rise to some of the most impressive military campaigns in history. Nevertheless, armies are highly consumptive of supplies (not just weapons, but food as well), and so they persist only through constant conquest, or the support of a taxable region. The economic advantage of a city or state should be clear in this regard; they could continue their investment in armies and navies, as well as the development of more advanced weaponry.

The rise of states and empires is deeply tied to the development of security technologies. The Romans established their trademark system of roads across the Mediterranean and Europe not for trade, but for the maintenance of the Empire. Soldiers built the roads in order to quickly dispatch troops wherever they might be needed. Similarly, China's Great Wall served as an obstacle to northern invaders, and as a means for communication and troop movement. More recently, the development of the professional army and the creation of ocean-going warships contributed significantly to the rise of European nations and the colonization of much of the non-European world. In turn, these states came to realize the importance of the continued development of both technical and organizational means for maintaining or disrupting regional security.

This inter-relationship between warfare and the modern state cannot be understated. When we think about the weapons of the early modern period, cannons, wooden sailing ships, and fortifications, we may think these technologies quaint, but they were cutting-edge engineering. They consumed the better part of many nations' tax revenue. Indeed, all three examples were, at one point or another, the subject of early research and development programs, though the rulers of the time did not conceive of such experimentation and innovation in the same way we do now.

The development of fortifications and the utilization of cannons played a strong role in the creation of military engineering (and vice versa). In terms of the establishment of a systematic body of engineering knowledge, and the institution of engineering schools, military engineering predates all others. Military officers had to know mathematics and geometry for the arrangement of fortifications, and the calculation of gunnery ballistics. Indirectly, this is where we get the name "civil engineering." Though we use it now to cover the design of bridges, roads, dams, and tunnels, the phrase was first used to distinguish it from military engineering.

Likewise, in the age of discovery and colonization, nations invested not only in the development of more capable sailing ships and lightweight ship-based cannons, but also on the "software" side. They paid for cartographic and hydrographic expeditions. They established schools of navigation that developed tools and techniques for the common sailor. They funded the search for ship-based chronometers, something that resulted in a kind of early international competition. Though state sponsorship of exploration and its technological means was an economic endeavor, the reality was that the two went hand in hand. Conquest, whether by army or navy, expanded the edges of empire, tempting nations with the promise of greater wealth. In many cases the trading companies of the colonial empires also acted as defacto military arms.

Earlier I briefly mentioned how changes in weaponry or defensive technologies could result in a rebalancing of a tactical situation. If a thief learns a new method of breaking into a home, the homeowner will attempt to develop an improved response. Likewise, state development of advanced military technologies has, for hundreds if not thousands of years, been part of a constant competition over both tactical and strategic balance. When I say tactical, I am thinking about changes that would impact the order and execution of a battle. When I say strategic, I am thinking about the large-scale balance of power (of which tactical is one component). The point is that nations continually attempt to shape these relationships, often through the development of new technology, but also through organizational means that somehow limit the creation and/or deployment of technology.

To provide a specific example, after World War I, nations sought to limit the potential for an arms race, which many people believed contributed to the outbreak of World War I in the first place. Through treaties, they established quantitative and qualitative limits on the armies and navies of different countries, specifying, for example, such things as the number and size of battleships. A generous view of the treaties sees them as attempts to balance the military power of each nation, thus creating a stable system. A more cynical view sees the treaties as a way of embodying a strategic imbalance, one that benefited the victors of World War I.

More recently, the Cold War showed us how the nuclear weapons of two great countries could be used to shape international relations across the globe. The very premise of the Cold War was that the cost of a "hot war" would be too high, that if the Soviet Union and the United States actually went to war with each other, nuclear holocaust would destroy much of what the countries sought in the first place. Between the two countries they attempted to out-do each other in their military might, a weapons competition that reached absurd proportions when they built enough nuclear warheads to destroy life on earth a number of times over (many of these warheads remain with us). Between the two superpowers was a fragile peace, one embodied in the concept of "mutually assured destruction" or MAD. It was not until the second half of the Cold War that the two countries began establishing alternative means for preventing war. This included the institution of treaties, parts of which employed advanced technological systems for monitoring the enemy's activities.

Industrialization, Modernization and Globalization

Despite the historical continuities that I've stressed in my overview of security, the story takes a number of interesting and troubling shifts in the last two hundred years. The rise of industrialization, the unfolding of modern society, and the increasing spread and confrontation of ideas and technology, bring us to a point where security concerns are qualitatively different from what they were for our ancestors.

Industrialization had a number of effects on warfare. Directly, factories and associated technological developments became technological inputs to quantitative increases in weapons, as well as qualitative changes in killing performance. Indirectly, increasing state revenue from industrialization permitted ever-larger military budgets, and fed a growing appetite for colonies that could supply raw materials and markets.

Warfare also found inspiration in the principles that drove industrialization. In the late 19th century, inventors began applying the idea of mechanization to the technical challenge of killing people. One result was the machine gun, which the nations of Europe first put to extensive use in World War I. This war in particular became a symbol of industrialization gone awry. It would be World War II, however, in which the economic principles of the factory became applied to killing. In Nazi Germany's effort to eliminate Jewish and minority peoples, they created efficient killing machines using gas chambers. Bullets, they found, were much less efficient, both in terms of labor and materials.

Today, killing and warfare have become available to a mass market of insurgents that thrive in, and foster, regions of instability. Raising an army costs a fraction of what it used to (though actually winning a war often takes a bit more). AK-47's, grenade launchers, guerrilla tactics, and willing youth are all many groups require. The arms are easily acquired from firms and nations all too willing to exchange ethics for profit. And in many cases, these regions of instability are part of larger, longer-term competitions for regional and global supremacy, including European colonial expansion and the Cold War.

I am using modernization as shorthand for a number of changes that are part and parcel of the history of industrialization. The first one that I would like to point out is that the political empowerment of the individual occurred simultaneously with a new level of technological empowerment. One thousand years ago, a single individual (as opposed to a leader of a movement) had quite limited means for causing widespread destruction (save arson). Modern weapons, however, greatly amplify an individual's ability to kill or cause economic damage. Some such weapons are available in the marketplace (e.g. machine guns), but others require only an education and the will to hurt others. Indeed, as the destruction of the World Trade Center Towers in New York showed, the means for killing thousands of people can come merely from the rearrangement and redefinition of existing, peaceful technologies. There are, now, many ongoing efforts to ensure that peaceful technologies cannot be redefined for ill purposes. A simple example of this, which goes back to the 1980s in the United States, was the development of tamper-proof containers for food and medicine. These came to the marketplace after a number of deaths caused by the addition of poison to the product.

A second feature of modernization is the dramatic increase and cost of non-physical threats to security. By this I am referring to attacks that are carried out on the information infrastructure upon which our modern economies depend. These may first appear less malevolent or harmful than actual physical attacks, but the damage is quite real. A good example with which we are increasingly familiar is the malicious computer virus. A person can cause millions of dollars worth of damage across the world. The cumulative human cost (in lost jobs, lower wages, failed companies, declines in productivity) is difficult to see, in part because the attacker is physically dissociated from the points of impact. Modern warfare, interestingly, has also taken on this quality of dissociation, what with remote sensing, unmanned aerial vehicles and precision munitions. Killing becomes frighteningly similar to a video game, and indeed, the US Army is using video games to both attract and train new soldiers. Information security and physical security have thus become intertwined.

The last qualitative change in security, I believe, is that the globalization of economic and technological systems is creating a world in which local and regional (or global) security become tightly linked (and in some cases indistinguishable). In a less networked world, the ills of one person, city, or region were surrounded by spatial buffers that reduced, and in many cases completely isolated acts of violence. This is clearly no longer the case. Not only does such tight-coupling mean that violence ripples across unconnected localities, but that the network world might be manipulated, redefined, and/or rearranged in a way that could serve destructive ends. It could become, perhaps, the ultimate amplification of individual anger.

Security Complexes

I alluded earlier to the way in which different societies combine technology with institutional measures in order to maintain security. We would be very mistaken if we believed that every security threat required a technological response. Our world would become a system of walls and checkpoints, a maze of devices burdening the civil operation of society. But with surprising ingenuity, we have been able to swap artifacts with invisible institutions, to substitute the knife for a code of conduct, a legal system, or religious order.

Similarly, security complexes also characterize regional relationships in which different states employ a mix of technological and organizational means in order to establish a framework for peace (or perhaps subjugation). The Strategic Arms Limitation Treaties (SALT) represent the most famous example of this. The Soviet Union and the United States agreed to reduce the number of ballistic missiles in a fashion that would retain the MAD relationship. That is, the two countries could still destroy each other many times over, but they could reduce the number of warheads and missiles standing ready.

One of the amazing aspects of our larger security complexes is that we fold them into daily life in ways that make them nearly invisible. The tamper-proof bottle that I mentioned above is a good example of this. Each time I open a drink bottle or a box of food, I barely realize that I am removing a security device. Likewise, we build the institutions around us to handle a multiplicity of situations including real security threats. Security routines become contiguous with our other tasks. We don't think it at all unusual for a policeman or woman to be chasing a murderer one minute and writing a parking ticket the next.

Because the state has a monopoly on many security technologies as well as the most powerful security organizations (police, army), there is always a danger that the state will overstep its bounds and infringe on citizens' rights. This is especially worrisome due to recent developments in information technology. Where individuals now have the means to cause global destruction, governments now have the means to track the smallest details of our lives. These particular issues bring us conveniently to our next chapter on politics.

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Part Four

Putting People in the Machine

10 Politics

The behaviour of technology within society is complex and subtle. In ways that are not usually obvious to us, technology is packed with culture. Sometimes by accident, sometimes by design, we build technologies that reflect who we are and what we believe. In turn, these technologies become essential elements of our material world. The things around us do not exist as mere utilitarian objects, but as cultural determinants. Technology is not just what we use; it is who we are.

This chapter concerns politics, something that we might conflate with the earlier chapter on government. For us, politics is about power (and a few associated ideas as we'll see below). Insofar as government is about power, this chapter is also about government. But we do not wish to confuse the two, because the concept of power reaches far more places than do the structures of government. So to be perfectly clear, we will avoid the discussion of government in the chapter. Our focus is squarely on how politics (power) is built into technology.

Inscription and Prescription

Before we get into the details of political technologies, we want to have a general model about how society gets into technology (i.e. people in the machine). Our first idea is *inscription*, that when people go to design something, whether they realize or not, whether they do it purposefully or by accident, they do so with a specific world-vision. Designers have a mental image of how their technology will work, how it will be used, and how it will fit into the world. The design will match that image.

An interesting thing happens, however, when that technology is adopted by society-at-large. Because the designer has inscribed a world-view, the technology in turn *prescribes* a certain world order. In most cases, the act of inscription is unintentional. Designers typically only consider the more utilitarian aspects of their technology. And the small corner of the world they live in is generally how they imagine the rest of the world to be. There are also cases where designers intentionally inscribe a world-view into a technology. In doing so they are attempting to force the world to adjust – the technology becomes a vehicle for bringing about or preventing social change.

Elements of Politics

For this chapter we will consider five different aspects of politics: power, authority, membership, order, and freedom. Power and authority are very similar, but not the same. Someone can have the power to do something, but not the authority. For example, a burglar has the power to break into your home, but s/he does not have the authority to do so. Power is about the ability to do something; authority is about having an official right to do something. For the sake of this chapter we'll look at both at the same time. Membership refers to a person's access to something or some process. Order refers to the maintenance of stable social relations. Parents, for example, maintain order in a family. Finally, freedom refers to basic human rights, such as freedom of speech, association, privacy, travel, etc.

The typical conception of technology is that it is politically neutral. That is, technology has no political value in of itself; rather, it depends on how it is used. The problem with this assertion is that it suggests that technology can exist outside of human use. As this book has maintained from the start, there is no such thing as a technology devoid of human involvement. Technology always comes as part of a human package. If humans could act in a culturally neutral manner, than perhaps we could create politically neutral technologies. Yet we are all deeply grounded in one particular culture or another. The technologies we create will be a mediation between the natural forces that are general to all of us, and the cultural forces found in our specific locale.

As we shall see (in this chapter and the following two), the question is not so much whether technology is political (or gendered, or culturally biased) but to what degree. We can consider two possibilities. First, the political nature of a technology may be linked to the ambient culture in such a way that if we change the culture, we change the political orientation. Second, we may find a stronger link between machine and humans – that a particular technology always promotes the same politics or at least requires (or works best) within a given political framework. The scholar Langdon Winner has labelled this second class of technologies *inherently political*.[3]

We can illustrate these two ideas simply, though they have significant possibilities that we will explore further below. The first idea is obvious to anyone who has held a weapon. Let's imagine that you are in a room full of people and you have a 10-inch hunting knife. The knife places you in a distinct position of power over everyone else (assuming you're the only one with a knife). Clearly, the power structure changes if everyone

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[3] This chapter draws heavily from the work of Langdon Winner and David Noble who have written substantially on the topic of the politics of technology.

else in the room has a gun. Interestingly this is the kind of game that is played in international affairs when we talk about nuclear missiles and anti-missile defenses. Since World War II, nuclear weapons have not been used in battle, yet the mere possession of these devices, along with delivery systems and counter-systems, changes the world's power structure. Through the Cold War, stability (if we can call it that) was maintained between the US and the USSR through relative parity in nuclear capability. In essence, it was as if two people each had handguns aimed at each other. The first one to shoot would also likely suffer a parting shot from his enemy. This is why opponents of the US's anti-missile defense system argue that this will not increase security, because it introduces a destabilizing imbalance in military capability.

A good example of an inherently political technology is a ship. Power in a ship is not evenly distributed. The political structure is a hierarchy (a pyramid with power and authority at the top). Could we imagine it any other way? If a ship is travelling and the lookouts spot a looming hazard (perhaps an iceberg… use your imagination), would it be wise to take a vote on what to do? No, ships (and many similar technologies) require fast decision-making. A single authority needs to be able to decide to turn the ship.

Politics in the Machine

At this point you may be thinking "so what?" But our lives are filled with political technologies. They form a framework that determines many of our courses of action. Let's go through each of the areas we've defined and examine the impact that this has on society.

Our first area is power and authority. We've already considered the obvious example of weapons. But there are more subtle issues of power and authority. A car is designed such that one person is predominantly in control of its operation. We could design it differently and decentralize the operations. Like the ship, however, we realize it is important for a single person to be able to make quick decisions about the automobile's vector. Understanding how a technology distributes power gives us clues about its politics. Does the technology lead to a centralization of power/authority? Or does it lead to decentralization? Consider the design of classrooms. On the one hand there are small rooms with level floors and movable chairs that can be individually rearranged. On the other hand there are large lecture halls with fixed, sloped seating and a stage at the bottom. One of these locations is good for an open discussion; the other is designed to rigidly focus attention on a single speaker. Architecture is an excellent way to define a power relationship.

The second area is membership. Perhaps the best example of this (and one of the most important areas) is designing for disability. A 1994 study in indicated that 15% of the non-institutionalised population in the US have some form of disability that limits mental or physical activity.[4] One would expect a similar rate of prevalence for other countries. If when we design something we are only imagining a person with no disabilities, then we automatically exclude a portion of the population. They no longer have *membership* or *access* to the same technologies as someone else. Consider a person in a wheelchair. If we design a restroom that is impossible to navigate within a wheelchair, we have effectively said that such a person is not allowed to go to the toilet. The effect of this is not simply to cause an inconvenience. When the better part of our world is designed without disability in mind, we thus exclude disabled persons from most activities that we would consider normal (going to work, going out to dinner, etc.). In order to drive this idea home, the automobile manufacturer Ford has a "third age suit" that its engineers can wear in order to learn what it is like to be elderly. It restricts the motion of a number of different places (knees, back, elbows, etc.) and has goggles that simulate cataracts. The lesson for us is simple but fundamental. Designers of technology usually design for themselves – and it takes a lot of effort to get them to think about how technology works for other people.

The third area is order. Within social groups we have many different ways of maintaining order, for without order, society would decay into anarchy. Laws and customs go a long way to ensuring that we behave properly to one another. But they are not enough. So we have police forces that patrol about looking for anyone breaking the law. Even still, we do not have enough police officers to watch over everything, so we often turn to technology. If you look around as your travel through your day, you will see a world permeated by technologies that maintain order. There are walls, doors with locks, fences, barriers, signs and traffic signals. There are security cameras, infrared sensors, magnetic sensors, x-ray machines, metal detectors, door chimes, passwords and pass cards. We have vaults constructed with thick walls of concrete and steel in order to prevent bank robberies. We have toilet paper dispensers that provide only a few sheets at a time – so as to prevent toilet paper robberies. All around us we design

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[4] Mitchell P. LaPlante and Dawn Carlson, "Disability in the United States; Prevalence and Causes, 1992" Report #7 (August 1996) Disability Statistics Center, University of California at San Francisco.

technologies that not only serve utilitarian functions, but also limit and circumscribe our actions.

Finally there is freedom. Are there technologies that impact freedom of speech? Privacy? Assembly? Travel? Certainly we can see differences between the technology of television, which has fairly centralized programming, and the Internet, in which anyone can be an author. Does this suggest that the Internet promotes more freedom of speech than the television? Perhaps. As for privacy, there are definitely technologies that can limit privacy, as well as enlarge it. The rise of information technology has led to a definite decrease in privacy as our actions are increasingly documented and analysed. How about assembly? Are there technologies that allow us to more easily form communities of like-minded individuals, to do so freely and without fear of repression? And then travel… there seems to be no question on this point. Technology has permitted a greater degree of travel freedom (though a cynic would note that the same technology is making the world homogenous, thus defeating the purpose of travelling in the first place).

Mechanisms of Inscription

We've already seen a number of different ways in which political values are inscribed. One is where the utilitarian function and the politics are the same. A gun or locked doors fall into this category. Another is when the politics are accidental: on the way to providing something useful, the designer also made something political. Most structures that lack wheelchair access fall into this category (though this is no longer an excuse given the widespread knowledge of disability standards in the construction industry).

We haven't considered technologies that are dual-use. These have a primary function that is usually utilitarian, but also carry out intentional political programs. There are some well-known examples from history that fall into this category. Parisian boulevards are famous for their beautiful vistas. They are wide and radiate out from the city center. Of course all cities need roads for the transport of people and goods. And while we may interpret Parisian roads as an example of good aesthetic design, they were in fact arranged and sized for the quick dispersion of troops to control citizen uprisings. The streets of Paris aren't just about transportation, they're about control. On Long Island in the US, the bridges over the Long Island Parkway (highway) were constructed very low to the ground. The secondary political effect was to prohibit buses from using the Parkway –

and thus exclude a certain demographic group (the poor who used buses) from easily accessing Long Island.[5]

Interestingly, not all political inscription occurs at the design level. In some cases, the inscription is neither accidental, nor the result of the designer's intention! The politics may simply be the result of larger organizational frameworks that favor one design (or technology) over another. Funding for R&D, for example, does not flow evenly to all projects, but is instead directed by governments and corporations to projects that serve certain interests. We should not be surprised if these R&D efforts result in technologies that change or strengthen political relationships. In the same way, larger societal frameworks (power structures) can become mirrored in the technologies we create.

Inherently Political

The most radical proposition we can make in this chapter is that a particular technology always promotes the same politics or at least requires (or works best) within a given political framework. What is it about the technology, or the circumstances that make it inherently political? Or is it a function of the people using it – that we act in predictable ways regardless of culture?

The case of the ship, car, and airplane suggests that speed of decision-making is an important factor in the political structure that controls the technology. This idea will be taken up in chapters eleven and twelve. These are not the only places where technologies are accompanied by centralized, hierarchical structures however. With most large-scale technological systems we see hierarchical control. Indeed, it was early forms of information technology (the telegraph and telephone) which first permitted the growth of modern firms with hierarchical management systems dispersed over large geographic areas. This occurred first in the railroad industry. Large technological systems tend to be operated as hierarchies because it is efficient; like the ship, these systems cannot waste time and money deliberating about a course of action. Centralized decision-making is fast, and the hierarchy permits quick implementation of policy (regardless of the worth of the policy). So it is our drive for efficiency, expressed most strongly in the capitalist economic system that pushes us towards economic and technological centralization.

Still, there appear to be numerous technologies that, regardless of economic system, impose political centralization in their operation. Nuclear power (not the solar kind), for example, is not the sort of thing that any

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[5] See Langdon Winner for more information on these examples.

country places under democratic control with easy public access. Nuclear power is simply too dangerous to trust to all individuals, since we know that society harbors persons who would not hesitate to use nuclear power for ill. The reactor waste and reprocessed fuel could be used for terrorist ends. And so we create structures around nuclear facilities (physical and organizational), which exclude the public and place reactor design and operation beneath government hierarchies.

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11 Gender

Gender refers to the sexual characteristics of someone or something. People have gender, and so do artifacts. That technologies have gender may seem unlikely at first, since few things at the technical level exhibit any qualities we might readily associate with gender (save for the occasional male and female connector…).

We may begin by thinking about two different possibilities for gender and technology. The first, which we will term the *weak assertion*, is that technologies lack any inherent gender, but are gendered by society. As will be shown later, there is sufficient evidence to argue affirmatively for the weak assertion. The second, the *strong assertion*, is that technologies (perhaps not all, but some) can be inherently male or female. This latter argument is intriguing, but beyond the scope of this chapter. Such an argument would require, at a minimum, an exposition on what male and female is (beyond the physiological definitions) and how this is translated into objects such that the quality exists independently of the society that created it.

Of course, students often identify numerous technologies that are gendered simply because the objects interact directly with the human body. For men there are condoms and urinals, for women there are birth control pills and bras. While these might be taken as proof of the strong argument (e.g. find a society where it is common for men to wear bras), they succeed merely because men and women are physiologically different. While condoms and bras can tell us much about the sexual politics of a society, they are less helpful in showing the expression of gender in technology. Of more interest are those technologies that, at a technical level, could be of use to both men and women.

It should not take much convincing to see that the weak assertion is valid. Clothing is the most obvious example. To an alien visiting Earth, men's and women's clothing may appear strikingly similar, but to humans, there are subtle differences which all people take as cues as to whether something is for a man or a woman, and thus gendered. While functions and materials are more or less the same between men's and women's clothing, colors and styles are deeply gendered.

So what are the gender cues that are placed in our technologies to show that something is for a man or for a woman? Unless one subscribes to the strong argument, such cues are likely to be different from culture to culture. Thus a plaid skirt in Hong Kong is female, whereas a plaid skirt in Scotland is often male (the uniform of warriors past!). This difference among cultures is our first clue to understanding how technologies become gendered. However cultures devise their own rules (i.e. norms of behavior) is how technological characteristics come to be gendered. Despite the fact that these rules are not written down, or even explained in detail, individuals in society learn them as they grow up. A typical association is the color pink with women. If this is familiar to you (and it probably is) then try to think at what point in your life you were told that pink was a female color.

Table 11.1

A Rivet Gun	A Sewing machine
A Caterpillar Bulldozer	A Hoover Vacuum cleaner
A welding torch	A Stove
A Hard-Hat	An Apron
A Concrete Mixer	A Mixing Bowl
A Jack-Hammer	A Garlic Press
A Rolling Mill	A Pasta Maker

The gendering of technology extends to more than just colors and styles though. Its greatest impact is can be seen in how societies gender jobs. People often expect doctors to be men, and nurses to be women. They expect primary school teachers to be women, and construction workers to be men. All societies carve out gendered spheres, and the technologies that go along with these job environments are many times, gendered as well.

Take a look at two columns in Table 11.1. If in your imagination you see a man using all the technologies in the left column, and a woman using all the technologies in the right column, than you are implicitly recognizing gendered work environments. We expect construction sites to be filled with men, and we expect the home to be run by a woman. One of the interesting aspects of this is that it is not necessarily the activity that is gendered -- it's the physical place of work. Take a look at Table 11.2:

Table 11.2
Gendered activities, or gendered spaces?

Activity	Female	Male
Cooking	A parent preparing dinner at home	A chef preparing a gourmet meal at a restaurant
Healing	A parent caring for a child at home	A doctor caring for a child in a hospital

The astute reader will also recognize that the change of location also involves a change in profit potential. While working in a home is an economic activity, it does not generate dollars in the same way that being a chef or a doctor does. Such patriarchal patterns in history are not unusual (to say the least).

Going beyond the home, we see that in factories, stores, and offices, jobs continue to be gendered. The teller at a bank is likely to be a woman. The seamstress in a textile factory is likely to be a woman. Their bosses are likely to be men. The secretary in an office is likely to be a woman. The list goes on and on. We make think of all of these as technological activities, and we may consider whether society places a gender value on the associated artifacts.

How does gendering start?

Before getting too far into a gender mapping exercise, it is worth delving deeper. How is it possible that technologies and activities (which may be broadly defined as technological) can become gendered in the first place? Unfortunately, much of our evidence is anecdotal. We must also rely on historical analysis because the process of gendering is not one that we can view occurring quickly.

One recent example of gendering occurred in the field of computer science. Until the advent of electronic computers, computers were actually… women. In the 1930s and 1940s, women, employed in scores, were known as calculators, performing mathematical routines often related to gunnery ballistic tables or code breaking (cryptography). Even with the development of early electronic computers, women could be found rewiring the computers for new tasks (before computers were able to run stored programs, the routines were "programmed" by changing the wiring combinations). It was not long before men almost completely displaced women in the computing field. Aside from extraordinary figures such as Grace Hopper (developer of the first compiler), computing became a largely male domain. Indeed, it is telling that Grace Hopper was awarded the "Computer Man-of-the-Year Award" in 1969.

To explain this switch, we may consider why women were originally computers. First, they were less expensive than men, a trend that has unfortunately continued to this day in most societies. Why pay more for a man to do a job when a woman will do it for less. Yet this explanation is insufficient, since by itself, we would logically conclude that all jobs would be filled by women.

More important than pay are the historical attitudes about gender that existed when gendering originally occurred. In the case of the female computers, women were considered (predominately by men) to be better at repetitive, routine tasks. Non-routine tasks would have required problem-solving ability, something that male managers obviously did not trust to women. Through history, we see that such opinions about gender change. In some cases we see that women are supposed to be good at work that requires great dexterity (yet we do not fill the ranks of surgeons with women). In other cases we are told that women are unable to withstand the rigors of hard, physical work (despite the fact that women have worked alongside men at the same jobs for millennia).

In some cases, gendering is strongly tied to traditional roles within the family. Men and women are not the same, and the predominate difference is in child-rearing. Women bear children, and women, more than men, tend to have a stronger day to day link to the care of family members. Thus we associate some nurturing activities with women, rightly or wrongly. For example, between the stereotypical male doctor and the stereotypical female nurse, we expect the nurse to be the one that provides loving care. The doctor, by contrast, is a clinical expert whose word we are to trust and obey. His opinion comes from the mind, not from the heart.

It is beyond the scope of this chapter to fully explain how things and activities become gendered. For our purposes, it is enough if we become attuned to the fact that this is something society does, and to recognize it in the technologies and technological activities around us. At the very least, we should understand that patriarchy and social context, as well as some biology, come into play in the act of gendering.

Transmission and Reinforcement

While our understanding of how gendering begins may be vague, we are on firmer ground when it comes to transmission and reinforcement. That is, we understand how these cultural values are transferred from generation to generation. Not only do we continue to propagate gender messages throughout society, in some respects we amplify them, making the message stronger for future generations.

One of the classic examples from the history of technology involves the development of housework, and especially the definition of cleanliness. Before the advent of vacuum cleaners, clothes washers, electric irons, specialty soaps and cleansers, people had, by contemporary standards, a lower level of cleanliness. For example, in the West, the major household cleaning event was "spring cleaning." As soon as it was warm enough outside, the entire house would be cleaned, rugs removed, hung outside, and beaten. It was an event, interestingly, in which all members of the household would partake (not just the women). Such cleaning chores were not the weekly events (or more frequent) that they have become today. Not only have our standards of cleanliness become more exacting, but they are, in many industrialized societies, closely tied to female work. How did this happen?

To make a long story short, we need to imagine the development of modern manufacturers, chemical companies, and advertising agencies. These groups developed and marketed new household technologies (vacuum cleaners, refrigerators, cleansers), and their principal targets were women. We should not be misled into thinking that women were passive victims of a capitalist conspiracy. Women were not helpless, but bought into the manufacturers' and advertisers' vision. These companies were, after all, picking up on existing gender roles and amplifying them.

The message (and vision) that the companies sent was that women were guilty of there duties (as wives and mothers) if they did not provide the cleanest home possible, with the best meals, the healthiest of environments, etc., etc. This is a story that should be familiar to all of us -- simply turn on the television and watch the advertisements for home products or, better yet, leaf through a magazine on household care or parenting. You will see appeals to women that encourage them to increase the level of cleanliness. Implicit in many of these advertisements is that wives and mothers who do not create a happy, healthy home are guilty of husband or child neglect.

The great irony about household technologies is that they were often sold with the promise that they would decrease the amount of housework. In the end, the amount of housework actually increased, since social definitions of cleanliness (and a host of other things such as diet) changed. Our homes are now filled with technologies that we are supposedly, unable to do without. These technologies are largely gendered female, thanks in part to social attitudes but especially to capitalism and modern advertising.

Gender and Engineering

Household technology is only a fraction of all gendered activities. One of the most critical areas is engineering, where we find a preponderance of men. This has special ramifications for all of technology, because if the activity of engineering is largely gendered male, we are not only missing out on much of the talent pool, we may also be designing a world full of male gendered technology.

Despite strong efforts in many countries to change the gender imbalance in engineering, women continue to make up between ten and twenty percent of the profession. Women are consistently under-represented in engineering, more so than most other related fields such as medicine or science. Whereas woman have made deep inroads into many professional fields, engineering in many ways represents the last frontier for female equality. To some extent we can assign blame to discrimination, but for reasons explained below, many women never even consider entering the field of engineering.

One immediate result of this is that the field, and the creation of new technology in general, is limiting itself to a smaller pool of talent. This is a real concern for a profession that continues to experience labor shortages. Why should society (or an economy) cut itself short by only drawing from half the population? Clearly we need to renew our efforts to increase the number of female engineers, which means attempting to understand why many women do not enter the profession in the first place.

A second long-term result of fewer women is that technology itself may be different because it is largely male designed. This argument will not make sense to you if you believe that technology is culturally neutral. One of the main points of this book, however, is that technology is not neutral, that we build into it our own values, our own vision of how the world works and how we want it to work. We know already that engineers can lose sight of specific groups of people when they design. This is why some architects occasionally fail to make buildings wheelchair accessible -- they forgot that not everyone has use of their legs. This is why the Ford automobile company makes use of an "elderly person suit," a device which slows and limits the range of physical motion. The suit shows young engineers what it is like to be elderly and use an automobile.

We can hypothesize at least three different ways in which a predominantly male engineering profession could "build in" characteristics of their own gender. The first and most obvious one is designing around male physical characteristics. This would include making something that fits men, but not women, or designing something that men are comfortable lifting, but not women. A second way that design might be different is in the choice of technologies. There may be technologies that men are attracted to, and others that they avoid. For example, there seems to be no shortage of interest in aerospace technology, but the same cannot be said for child-rearing technology. Finally, we may think about whether being male or female leads us to design the same technology in different ways.

Table 11.3
Hypotheses About How Gender May Influence Design

	Female	Male
Physical design	Designs that fit or are appropriate to female physiology	Designs that fit or are appropriate to male physiology
Area of emphasis	Example: child-rearing technologies	Example: high speed aircraft
Emotional/social gender characteristics	Nurturing design?	Aggressive designs?

Is it possible that suggested male characteristics (competitiveness, aggression) find their way into products and that suggested female characteristics (cooperation, nurturing) do not. Clearly this last hypothesis is the most difficult because it requires that we make blanket assertions about what it means to be male or female (with the possibility that in our categorizations we reify gender definitions!).

Boys and Their Toys

So why are there so few women in engineering in the first place? A small part of the explanation comes from history. Professional engineering (and especially engineering education) was strongly influenced by military engineering in the 18th and 19th centuries. The military was clearly no place for women in these eras (save for the infrequent appearance of female warriors such as Joan of Arc). Even in civil engineering the top schools remained, for sometime, the military colleges and academies. For this period, women were effectively locked out of professional engineering. Non-professional (workshop or blue collar) engineering jobs were not much better, since these were usually associated with highly physical work. In the 20th century, many of these patterns have continued, despite the fact that an engineer's work is no longer physically demanding (no more so than the average businessperson's) and women have access to the same engineering schools as men.

Discrimination certainly exists in the engineering profession, but this does not appear to be the main contributor to the problem. Few women attempt to enter the engineering field in the first place. Something is occurring further upstream to discourage women. It is occurring even before women go to college, since admission rates to many engineering schools continue to be out of balance. Women are deciding that engineering is not for them when they are young.

There are two potential explanations: that girls are naturally not drawn to engineering, or that they are given signals by society that engineering is not for girls. The biological explanation finds most of its adherents in male chauvinism (e.g. "A woman's place is at home, not designing automobiles"). This book finds this explanation untenable. The second reason, social programming, makes much more sense, and we can find clear examples of it.

Gender programming begins at a very early age -- most noticeable in the toys we give children. Tour the aisles of a toy store and you will find a clear and distinct pattern: boys' toys are often related to building and constructing things; girls' toys are related to nurturing. Boys' toys emphasize the relationships between artifacts. Girls' toys emphasize relationships between people. As children grow older these patterns become amplified. Boys are often given models of things they can build. Girls are encouraged to learn how to cook. Boys continue on in learning how to fix things, such as cars. Girls continue on with learning how to take care of children (e.g. babysitting). These patterns of gender programming are extremely strong and in many cases cross-cultural. Imagine yourself buying a birthday gift for a nine-year-old girl, would you buy a doll or a plastic model of a car or tank?

Toys are a good example of how we teach children that technology is for boys and not for girls. No wonder that by the time girls are in high school, many have already decided that engineering is not for them. This programming creates other problems, however, since it gives boys a distinct advantage in the manipulation of technological artifacts. All the building and construction toys, all the playing with different machines (cars, computers) is what we call "tinkering," playing with technology. Tinkering gives people a familiarity with technology, even if the activity is nothing more than taking a machine apart. One finding related to tinkering is that even after women earn engineering degrees, they are sometimes at a disadvantage in the workplace because their knowledge is very much textbook knowledge. In the workplace, technology often involves hands-on problem solving. Many men, however, have had a great deal of hands-on experience when they were young, even before they began taking engineering courses.

The Challenge

It is clear that changes to the engineering profession, and to narrowly gendered technologies, will take time. Gender and technology are deeply ingrained in society; from generation to generation we see very slow changes. Our task is to recognize these patterns, and make certain that we do not exclude anyone when we design (and give) technologies. Our job is not to prescribe that a woman's place is in the home or in the engineering department, merely to provide the opportunity and the tools for each person to choose their own path.

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12 Culture

It has been the contention of this book that society is reflected in technology, and so we should expect to see distinct cultural values within technology as well. In this, culture and technology share many of the same characteristics as we saw in our previous discussions of politics and gender.

To anyone who is remotely cognizant of the world, it should be obvious that cultures have distinct technological styles. Clothing and buildings are perhaps the most obvious. The question we have to ask is whether these distinct styles are randomly associated with culture, or derive from some distinct cultural traits and values. And there is a corollary question: to what extent do these technologies continue to shape and define culture? Ultimately we find that understanding culture means simultaneously understanding technology – that the two are so inter-related that they lose their meaning if we pry them apart.

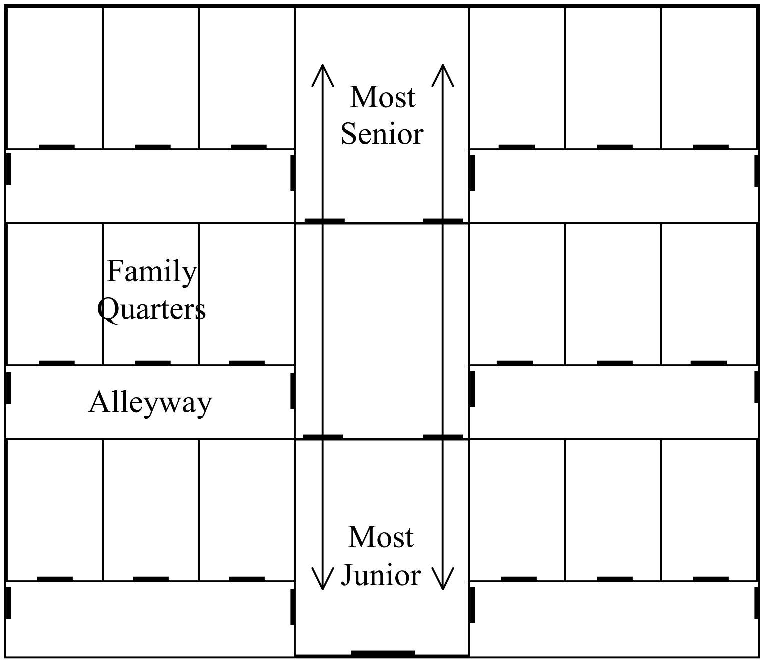
In exploring the relationship between culture and technology, we need to be very clear about what we mean by culture. To some people culture refers to the fine arts: symphony, sculpture, ballet, etc. In this chapter, the term is used more broadly to refer to a people's beliefs, practices, social relations, and patterns of behavior. This definition does not always provide us with easily identifiable boundaries. Sometimes cultural boundaries are somewhat synonymous with national boundaries, but often they are not. Within nations we find different regions with varied cultural landscapes. Linguistic boundaries provide some clue as to shared cultural values, but here again it is not enough. Within regions and within linguistic boundaries there is still variation – perhaps class, religion, race. A large cosmopolitan city may be situated within an identifiable national culture, but we would also expect to find a number of sub-cultures, some of which may hold views and beliefs contrary to the dominant national culture.

This chapter examines culture at two different scales, both of which I believe are powerful for understanding the link we are trying to establish. The first is a national scale; this presupposes that there is a continuity in beliefs and practices at a broad national (and thus geographical) level. The second is a local scale in which practices and beliefs are propagated and maintained among small groups of people, often arranged horizontally across different national or regional cultures. At the close of the chapter we will consider how technology and culture are bound up in two opposing trends: globalization and localization.

Architecture and Urban Design

The history of architecture provides a stunning array of the ways in which cultural values are given physical form and perpetuated over generations. A good example is the Chinese ancestral hall. The format of the hall is easily recognizable across China, despite the fact that there are regional variations. At the center of the hall is a long rectangular room constructed using post and lintel methods. The hall may have a number of sections, each becoming more and more private the further along one proceeds. At the rear of the hall one typically finds an alter table which formerly held a family shrine, but today is just as likely to sport a Mao poster. To the left and right of the hall are alleyways with the family residences. The further back one proceeds, the more private it becomes. To the left and to the right are the storehouses, servants' quarters, kitchens, and bedrooms. The quarters at the rear of the hall, and closest to the centreline, were reserved for the most senior family members. Often the next alleyway was reserved for successive generations (moving towards the front of the complex). Very similar formats were used in town planning, as well as the design of Beijing and the Forbidden City.

Figure 12.1
Simple scheme for Chinese ancestral hall



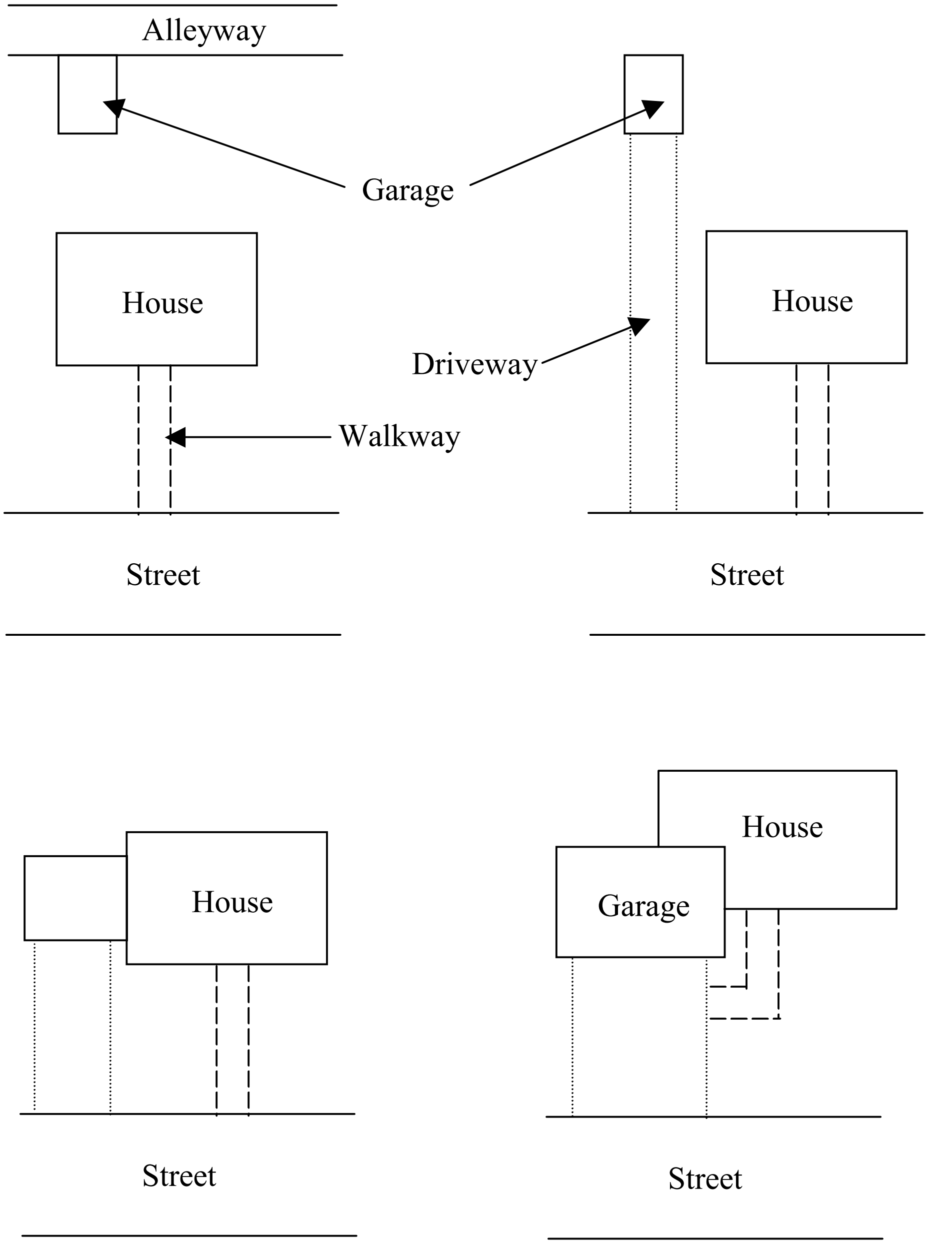
The persistence of the ancestral hall format derives from a number of factors. The first is its relationship to Confucianism, which places the family and ancestor worship at the center of life. The ancestral hall gives Confucianism a physical form (though it should be pointed out that this is not necessarily the only possible architectural response to Confucianism).

A second factor is building laws. Throughout China the Emperor maintained strict laws on how large halls could be made. Not just anyone could build a large hall. The largest were reserved for members of the imperial administration. A merchant, no matter how wealthy, could build a hall only so large. As in many cultures, architecture reflected a person's importance – but in China this was achieved through a highly standardized system that would have been recognizable throughout the country. To deviate significantly from this format would have been to invite punishment or ostracism.

A third factor is the building practices. As early as the Song dynasty there was a published set of building standards. The Yingzao Fashi, written by court architect Li Jie in 1103 (d. 1110) details ways of building that were first established as early as the Tang dynasty (8th century). These practices spread throughout China, and are one reason why post and lintel construction (more precisely, column-beam-and-strut) is so prominent. The guidelines established that this was the best way for making buildings. The positive effect of such guidelines is that it prevented builders from making structures that were unsafe – simply follow the guidelines and you could construct an extremely strong structure. On the other hand, guidelines can have the effect of inhibiting the development of new and radically different structures. This is especially so if the guidelines are presented as the final word on the best way to do something.

In previous chapters I have already alluded to some contrasting architectural forms. We can see the Egyptian pyramids, the Pantheon, and Gothic cathedrals as similarly reflective of the cultures that created them. With varying forms and construction methods, these examples of monumental architecture embody the values, religious and political, of their respective societies. But to provide a modern day contrast to the ancestral hall, let's take a look at the architecture of the US. There are many different aspects we could examine, but perhaps the most important is the shaping of the built environment around the automobile. The car has emerged in America as a symbol of independence, freedom, and faith in technology. Whereas the ancestral hall reflects the centrality of family and patriarchal relationships, American architecture and urban planning has, over the last century, been rearranged in a way that reflects the primacy of the car. The change has been thorough.

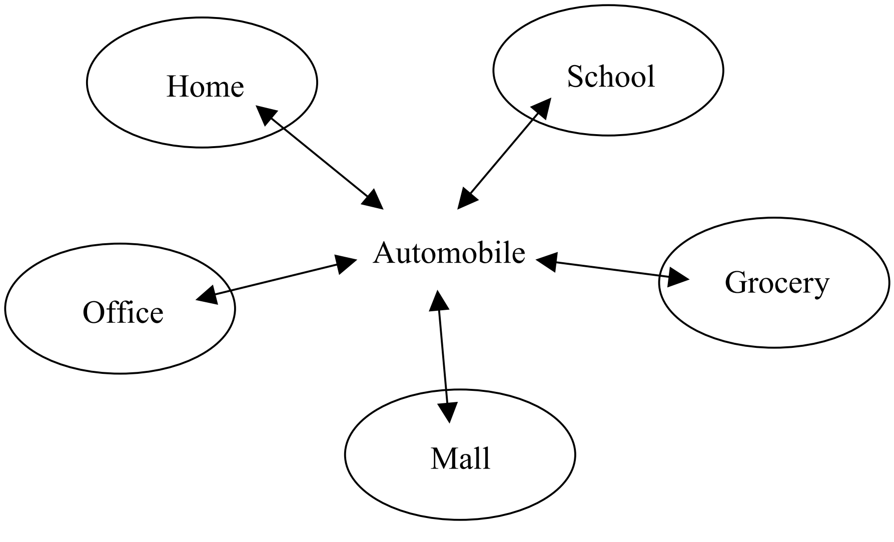
Figure 12.2
Progress and the American Home



When middle class families first began using cars, they did not typically have garages. The first garages appeared behind the house, and opened to an alleyway. With time, the alleyways disappeared, but the garages remained behind the home; a driveway connected the garage to the street in front. Going even further forward in time, the garage moved up closer to the house and was eventually connected to it. Today, many middle class homes are constructed such that the garage takes up the better part of the house's face, and to enter the house requires walking on the driveway.

As with Confucianism in China, the influence of the automobile (both real and symbolic) does not end with the home. We can consider the development of the *drive-through* restaurant in the 1950s. People so enjoyed their cars that they preferred to stay in them, rather than park, get out, and eat in the restaurant. Much better, they thought, to continue driving through the whole experience – to order the food, pay for it, and then eat it whilst driving. Two variations on this were the drive-in restaurant (in which waiters and waitresses served you while you stayed in your car) and the drive-in theater. While these latter two forms have not had much staying power, the drive-through restaurant is here to stay. With it we have *fast-food,* a particular kind of food production process designed to give the eater-on-the-go a quick bite.

Figure 12.3 Automobile life in the suburb



At the level of the community and urban planning, the automobile was instrumental in the development of suburbs – areas outside of the crowded city in which a car is an absolute necessity for daily life. In a city things are close together: the office, the grocery, the school. In the suburb one must drive everywhere. Not only are the distances far apart, in many cases, suburbs have few sidewalks for pedestrians (you must walk in the street). The development of the indoor mall (with its ample parking) was a byproduct of the automobile and the suburb.

The automobile itself is not a philosophy, but it represents a set of values that include a strong belief in independence and personal freedom, as well as a faith in modernity and technology. The car is about individual transportation, with *you* at the wheel. It is about privacy – your own space. It represents progress and a person's place in the world. Ironically, the construction of the world around the automobile has made the car a kind of prison – since we can no longer conduct life without it! With the growth of traffic jams and air pollution, the car shows us the length to which we are actually *dependent* upon each other and embedded within a highly interconnected world.

Technological Practice

We could spend the rest of the book discussing the different ways in which cultures create different artifacts. Certainly when we visit foreign lands one of the interesting aspects is the change of scenery and having to become accustomed to new sets of technology. But cultural differences exist beyond the shape and meaning of artefacts. It extends to the whole process of technological practice – including science and engineering.

We often think that science and engineering are value-free, but as this book tries to show again and again, these are value-laden activities. Scientists around the world may believe they speak a pure, universal language that crosses all national and cultural boundaries, but this is not truly the case. Scientists and engineers *have* succeeded in crossing many cultural borders, but they are not culture-free.

We often make the mistake of believing that because science takes place in a laboratory that it is dissociated from the world around it. Make no mistake, science aspires towards a dissociated objectivity – the ability to analyse something in a completely unbiased manner. Yet objectivity is never truly realized. The laboratory still exists within a social network, within a web of relationships and institutional frameworks. The laboratory is from the very start enabled by outside forces (government or private funding), which at a fundamental level begin to steer the kind of research that takes place. The interests of the scientists are very often the interests of society at large, or at least their government or corporate patrons. We can look at history to see how these cultural forces have thoroughly shaped science and technology in different cultures. For example, Chinese technology before the 20th century was strongly directed towards the practical needs of the country, leading to many developments in hydrology, agriculture, and medicine. By way of contrast, European technology in the last 500 years or so was heavily directed towards the equipping of armies and navies. The long-term results of these different emphases can hardly be disputed.

Today these larger institutional structures continue to influence the direction of research. Government and corporate funding is not spread evenly among all areas, but is focused on those that are expected to bring the greatest return for a society or company. The influence is more invasive than simple budget lines. The scientists and engineers employed to carry out the research are not independent actors, and in many cases must adhere to the organization's ideological stance. Robert Oppenheimer, who led the research team that created the first atomic bomb during World War II, became an opponent of US nuclear policy after the war. He was subsequently denied security clearances and effectively barred from participating in government funded nuclear research. When anti-communist sentiments grew in the 1950s, Oppenheimer suffered from being labelled anti-American. This is an extreme example, but we can understand how researchers, for example within a company, are expected to adopt the company's ideological stance. This has, as will be discussed in the next chapter, important ramifications for ethical behavior.

Even when organizations do not impose their values on their employees, we can see how cultural values seep into the laboratory. Scientists and engineers do not always leave their values "at the door" like some kind of raincoat or jacket. We choose research topics not only based on simple curiosity, but on whether such work will help the world, bring us riches, and/or advance our careers and prestige. These values influence our career selection, our research emphasis, and the manner in which we conduct our work. In the end, science and engineering respond in very dramatic ways to the priorities set by society at large.

A good example of this is the difference between automobile manufacturing in the US and Japan. Management and labor have long had a difficult relationship in the US. Managers and engineers at US automobile companies have historically sought to reduce the amount of skilled labor necessary to build a car (and in many cases eliminate the labor all together). What is essentially a power struggle between management and labor became embedded within the physical makeup and operating procedures of US companies. In Japan, however, workers have long been viewed in a more patriarchal manner. While workers were definitely subordinate, they were considered part of the corporate family. In automobile factories we find that, historically, Japanese workers receive much more training and are partners in the evolutionary design of the product and production process. These values have led to very different manufacturing set-ups and machinery. Political values are thus replicated on the shop-floor. And not surprisingly, when American automotive manufacturers have subsequently tried to copy Japanese methods, they have had to change not only the machinery, but the culture of the factory and company too. This is extremely hard to achieve, especially with so many decades of deep mistrust between labor and management.

There is another way in which technology is culturally differentiated. Rather than the top-down influence of society on the laboratory or workshop, we can think about a bottom-up influence of laboratory or workshop culture. This too works contrary to the notion that science and engineering practice are universal activities (rather than localized). Again, science and engineering may be *more* universal than other activities, and thus more easily transferable across cultures, but they are not impervious to the social forces that lead to idiosyncratic practices. To put this in simpler terms, individual laboratories and workshops tend to do things their own way. What this means is that these groups of people develop their own unique culture.

It has long been understood that firms develop their own culture, ways of doing things and ideas that are unique to that firm. To an outsider, two firms may appear very similar, but when a worker transfers between the firms, they often experience a dramatic shift in culture. These cultures persist within the organization over time and through successive generations of workers. Ways of doing things and ways of thinking become embedded in tacit procedures, in written guidelines and rules, even in the physical artefacts that make-up a company (such as the arrangement of offices).

Similarly, places where science, engineering, and other technological practices take place also succumb to cultural localization. Scientific laboratories try very hard to keep this from occurring by standardizing equipment and procedures. If you are familiar with the reporting of scientific experiments, you know that the authors do not simply include the conclusion, but detail the precise procedures, equipment, and conditions under which the tests were made. Without such strict procedures, other laboratories would not be able to duplicate the experiment and verify the results. Despite this, from one laboratory to the next there will still be differences. Laboratories working on the same experiments often have to communicate frequently and even transfer personnel in order to learn about these discrepancies.

These different cultures persist despite our best attempts to eliminate them. During World War II, different American aircraft manufacturers were asked to build the same aircraft. Everyone knew the task would be difficult, so they established a single set of precise diagrams that all of the manufacturers would have to follow. They also built master tools from which exact duplicates would be made (so as to standardize and maintain dimensional integrity). They visited each other to learn their respective practices. And they all received an example copy of the aircraft they were to make. Yet in the end, the aircraft they produced were different from factory to factory (though they would look exactly alike to the casual observer). How could this happen? The answer lies in the fact that these companies did not have much exchange before the war. Some engineers did move between firms, but for a few decades, the engineering and tooling departments of each respective company grew up in isolation. The machinery they purchased, the layout of the factory, the methods they established were each slightly different. Unlike scientific laboratories that have a strong interest in maintaining standardized procedures, factories merely seek to make products that work and sell at a profit. For these aircraft manufacturers, standardization was not a desirable end until the war began.

The Local and the Global

Different cultural expressions of technology and localization effects are interesting topics in of themselves. We can learn a great deal about ourselves and other people through comparative studies of technology and technological practice. We can also learn about the nature of technology – how it communicates and reinforces culture. For the last part of this chapter, however, I’d like to turn the discussion to what happens to the local in an era of globalization.

Globalization is a buzzword these days for persons both for and against the worldwide spread of technology and commerce. Proponents see in globalization a more productive and wealthier world, one that is tightly linked within a common economic framework. Opponents see, among other things, the destruction of local culture, the destruction of the environment (primarily in developing countries) and neo-colonial subservience to the developed world. My purpose is not to promote or indict globalization, but the debate provides a good opportunity to think about the relationship between the global spread of culture-laden technologies and the survival of local cultures.

Consider what happens when a technology moves from one culture to another. If we believe that technology is culturally neutral, then we could assert that the recipient culture can simply fit that technology into their existing social structure without incident. But if we believe technology is at all culture-laden, then we have to suspect that there may be a change in the recipient culture (and not simply a change in technological capability).

We can take the example of fast food that we had earlier in the chapter. In the city of Hong Kong, McDonalds seems to be on every other street corner. Its food is wildly popular. Does this mean that Hong Kong is turning into a car culture? No. But McDonalds (and fast food in general) *does* bring with it a number of cultural values that are slowly pushing aside the local. It goes without saying that food and shared meals are central to Chinese culture, more so than most western cultures. What happens when lengthy group meals are displaced by quick meals, usually involving a smaller number of persons? It isn't merely that the food has changed (perhaps for the worse) but that an important social institution has been supplanted. The meal is no longer a time for family members and co-workers to share their thoughts and renew ties. With fast-food, meals are to be made as short as possible. Time is for something else (work?). Even inside McDonalds we see the transfer of mass production food techniques established for an unskilled workforce. McDonalds' food production system is, like American automobile manufacture, infused with a political structure that places workers at a political disadvantage. It is no surprise than that McDonalds is one of the lowest paying employers in Hong Kong. Finally, the very act of eating standardized food (standardized across the globe) should be an obvious signal that globalization is erasing local differences.

Another excellent example of the force of global technology is the Internet. Before the Internet the English language was already established as the primary language for global commerce. But there were viable regional alternatives, including Japanese, German, French, and Chinese. Yet English was the dominant language for the Internet and computers (look at your keyboard if you're not certain). Since the late 1990s and the integration of the Internet into daily activities across the world, English is now the undisputed second language of choice (for non-native speakers). This is not the result of some linguistic conspiracy – it is a historical circumstance that computers and the Internet were developed primarily in the US. And it is a matter of technical economy that most Internet activities are conducted in one language. We could, of course, have web pages, software, and computer keyboards produced in multiple languages, but it is simply not economical. Or at least, we value the efficiency of one language over the benefits of a multi-lingual Internet.

Language is, as noted above, deeply tied to cultural distinctiveness. Language is a common bond among people, as well as a barrier to the spread of foreign ideas. The implications of a planet that speaks one language should be profoundly obvious. On the one hand, there is something stirring about a planet united – able to share ideas and communicate in a common tongue. On the other-hand, we lose our cultural distinctiveness, our cultural diversity. In the same way that it is unhealthy to lose biological diversity, so too we might be exposing ourselves to unknown dangers in our movement towards homogenous patterns of life. Not only do we risk the banality of living standardized lives, but also cultures across the Earth place their future in the same boat – perhaps making it more difficult for the world to experiment with alternative social systems.

Globalization, of course, is both a powerful force that seems to have its own momentum, and a personal choice. We are simultaneously victims and agents. We are victims of history – born to certain cultures and subject to their material conditions. We are also eager participants in this modern technological experiment. The following three chapters explore our place within the overall technological decision making framework that makes modernization and globalization possible.

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Part Five

Failure and the Future

13 Ethics

Ethics is about acting in a moral manner – doing right and wrong. What is and is not ethical is defined by society. There are some actions that most societies consider unethical (murder, for example). There are other actions, such as polygamy, which vary depending on the society in question (permitted in some, and scorned in others). Ethical conduct is rooted in many different sources: religion, laws, customs and traditions. Some people act ethically because they believe that some things simply are right or wrong (a normative standard). Others act ethically because they believe it a factor in social stability and harmony. And there are yet others who may not actually believe in ethics, but act ethically because it serves their best interests.

Within the area of technology we have a number of different applications of ethics: science, engineering, and medicine. Each of these communities has their own ethical standards and codes of practice. These are enforced through both professional and legal measures. This chapter introduces ethical problems in all three areas, but focuses primarily on questions of engineering ethics. Engineering ethics are not only of interest to engineers, but to all of society since we interact daily with the designs and products of engineers.

Ethical Science

Ethics can be applied to science in at least two general situations. The first involves questions of responsible behavior in the conduct of experiments and the reporting of results. For example, a scientist may act unethically by stealing data from another researcher, by changing data so as to fit a desired outcome, or by skewing the direction of research in order to benefit a particular commercial interest. Such actions involve the misappropriation or the corruption of knowledge. Since the basis of science's influence on society is its ability to produce highly accurate information (at least more accurate than most other knowledge producing activities), unethical behavior reduces the legitimacy of science. It corrupts not only the authority of the unethical researcher, but the knowledge and practice of science as a whole. Thus, scientists attempt to maintain high ethical standards as a means of ensuring their authority as well as the quality of their products.

There is a second general area of ethics that applies to science: whether particular areas of research can themselves be unethical (even if the research is conducted in entirely proper ways). Under what conditions is it ethical, for example, for scientists to do research that may lead to human deaths? Nuclear weapons research is just one example. In the 1940s, physicists and chemists gathered in the United States, along with scores of engineers, to do research that would ultimately lead to the design and construction of atomic bombs. In the rush to aid in the war effort, few scientists questioned the ethics of their actions. They saw themselves in a fight to defend the country. Only after the weapons were built did some of the scientists begin to express strong disagreement with the direction of research. Yet by then it was too late – since the knowledge to produce the weapons was already known.

This begs the question. Realizing that knowledge can have *real* and *dramatic* consequences, are there some forms of knowledge that we are better off not knowing? It is a difficult question because knowledge, in its abstract form (made real initially through words, data, and drawings) does not appear to have a significant relationship to social outcomes. Imagine a scientist who discovers a simple way to create an extremely hazardous biological agent (that could kill large numbers of people quickly). Knowing that the world is full of people who would use such information to kill indiscriminately, what is the proper way to handle such information? Should it be kept secret or destroyed? Should it be reported to other scientists? To the police? To the public in general? Thus, to restate the question, in a world where knowledge has predictable social outcomes, what ethical responsibilities do scientists have to direct research and the production of knowledge in certain directions, and away from others?

Ethical Medicine

Because medicine directly impacts the health and lives of people, ethical issues are more obvious, though no less tractable. Like scientific research, we can divide medical ethics into two general categories. The first involves the conduct of doctors and medical researchers. This covers many of the same issues that were raised above, such as honesty and conflicts of interest (e.g. a conflict between the interest of medical science and commercial or personal gain). It also involves, to a greater degree than most scientific practice, the question of how to do experimental research on humans. How is research conducted ethically on humans – research that could have potentially damaging results? Typically this involves gathering as much information as possible before using human subjects, and finally, when it does reach the human test stage, peer review, and full disclosure of such risks to the test subjects (who can opt out of the test if they desire).

Like science there is a second area of ethics that questions whether particular areas or practices within medicine are morally acceptable to society. Is it right, for example, for a doctor to assist in a suicide when a person is in extreme pain due to a medical condition that cannot be cured? Is it right for medical researchers to attempt human cloning? To what extent should human fetal tissue be used to cure disease? Should doctors permit parents to select the gender (or even other characteristics) of their unborn children? And what authority *does* a doctor have for making decisions for a patient (especially when the patient will never really understand the medical problems as well as the doctor)?

Ethical Engineering

In contrast to scientific and medical ethics, most questions pertaining to engineering ethics relate to issues of practice. It is rare for engineers to become involved in questions of whether certain areas of engineering or whether specific engineering projects are ethical or not. This reflects, to a large degree, the fact that engineering and engineering professional societies have had strong historical links to business. Engineers have long been the technical handmaids of industry – and in terms of ethics, the marketplace is usually characterized by market failure. That is, businesses exist to make money – not to uphold particular social standards. Strictly speaking, we expect businesses to act ethically only when it impacts their revenues. Where the marketplace does not impose its own standards, we see the imposition of government regulations (e.g. consumer protection, workplace safety standards). The relationship between engineers and business strongly influences the types of ethical problems that arise, as well as any attempts to define and correct unethical behavior.[6]

Most engineers are members of two worlds: a professional engineering community, and the business community. We can think of counter examples, such as university faculty that carry out engineering research, but even here research orientation is often directed by corporate donations, and faculty often have strong links to the corporate world. The split personality of engineering raises questions of moral autonomy: do engineers have the authority to make ethical decisions on their own? Consider, for example, what would happen if an engineer decided that a particular project was unethical, and the engineer decided not to carry through with the project. Almost without fail, that engineer would be

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[6] While this discussion focuses on engineers, we could just as easily include scientists and doctors who carry out engineering activities within a business context. The professional training has less to do with the issue than the activity at hand.

dismissed. There are thus negative repercussions for engineers who act on ethical beliefs inconsistent with a company's values (which may amount to nothing more than "make as much money as possible"). Engineers are therefore expected to follow the company line – to act according to company directives.

Yet the situation is more complex than this, since engineers are not allowed to blindly follow company policies. Indeed, as members of the engineering community, they have certain obligations to the public. In situations involving human safety, engineers are supposed to act in the interest of society. Engineers who act unethically within a company cannot hide behind a company shield. Should the unethical activities be uncovered, both the company *and* the engineers may be prosecuted. And unfortunately, in all too many circumstances, the company shields itself from prosecution by localizing the problem at lower levels. In order to save the body, they will cut off the leg (by blaming the engineers). It can be a no-win situation for the engineer.

Over the past few decades, a field of study has grown-up devoted to the questions of ethical engineering. Many university engineering programs now require that engineers not only be technically competent, but that they understand the difference between right and wrong. Unfortunately, much of the work in engineering ethics remains rooted in anecdotes about technological disasters. These are interesting and can be instructive. But as historical episodes that will surely not be repeated in exactly the same manner, they are limited in application. The reality is that engineers are thrust, often daily, into gray-area decisions where they must weigh the public good against corporate profits. *Most* of the time, small engineering decisions do not result in horrendous technological disasters. After a while engineers often become unaware of how close their decisions are to the ethical edge, and don't realize when they've gone over. When disasters do occur, it is all too easy in hindsight to pick through the evidence and locate the exact decision that caused everything to fall apart. Looking backwards we can identify the warning signs that the engineers *should* have seen. Yet in the midst of the decision making process, and after years of making many apparently successful judgement calls, these warning signs and mistakes are not so obvious, and in some cases, nearly impossible to notice above the noise of the average workday.

The study of ethical engineering has an additional disadvantage in that it tends to ignore the larger structural issues surrounding engineering failures. We have not, for example, found alternative managerial models that could be used in businesses that offer additional public safety without additional costs to the company. In the forensics of engineering failures, we tend to focus on the micro-decisions that led to disaster, rather than asking whether the larger technological system is itself more prone to failure than others. We often fail to see that ethical failures come at the end of a long list of poor decisions; the engineer with the ethical lapse was at a distinct disadvantage to begin with (and in some cases, faced with decisions he or she could not safely resolve). If there is a distinct message that comes from the study of engineering ethics, it is that being forced to make risky decisions (for which you are ultimately responsible) is an occupational hazard in the engineering profession.

Making matters worse, while many poor engineering decisions never result in disaster, being *overly* safe can result in severe career difficulties. Engineers that report ethical problems (we call these people "whistleblowers") within the company can become known as troublemakers (with consequent demotions), or even worse, fired because their views clash with corporate goals. Engineers that make public their misgivings are almost always fired – even in cases where they were subsequently proven correct! When tragedies result – these same engineers are often accused of not having done enough. When tragedies do not result, they are accused of being over-zealous (or worse, pursuing a personal vendetta with the company). Some governments and some engineering societies have tried to create protections for legitimate whistleblowers, but justice for such persons is often long in coming. In the meantime their careers are turned upside down, and they are torn from the work they enjoy. Moving to another company is often not an option – who wants to employ a troublemaker?

What are the Standards?

Ethical standards within engineering are defined primarily by professional societies. Again, these are strongly influenced by business interests. Perhaps not surprisingly, the ethical standards for engineering differ from those of science and medicine. Businesses are not normally interested in employing social activists. Thus we find that the definition of "ethical behavior" for engineers is much narrower than for scientists or doctors. For example, a scientist who intentionally publishes inaccurate information would usually be guilty of an ethical violation. A corporate engineer who publishes inaccurate information in order to make a sale, on the other hand, may be acting fraudulently, but not violating ethical codes of conduct.

The general litmus test for ethical actions in engineering is whether there is a possibility of serious harm. The definition is thus highly restricted to issues of safety. This does not mean that an engineer is free to commit non-safety related offenses, just that they fall under codes of business practice rather than engineering practice. But how safe is "safe"? There is always a risk that something will go wrong. We could design aircraft with an emergency exit at every row, but then the plane would be so heavy that it wouldn't make money. So we make concessions for the sake of profit. How far do we go? What percentage of the time is it acceptable for most of the passengers to die in a crash? On average, should 30% survive? 60%?

The general rule is that risks to safety *must be known and judged acceptable*. Nobody should be placed in circumstances in which they are not aware of potential dangers. Once the risks are known, people need to be able to opt out – no one should be forced to partake in an activity they consider unsafe. This rule nicely avoids one of the problems of risk: we all assess risks differently. Some people are willing to climb mountains or ride bicycles in heavy city traffic. Others are not. Furthermore, we tend not to be consistent in our individual assessments of risk. One of the most dangerous activities we do daily is road travel – yet we do it without thinking. Flying commercial aircraft is far safer, yet we tend to get worried about aircraft accidents much more than auto accidents. The above rule leaves many risk and safety decisions up to participants, but it leaves the engineer (and company producing the technology) with the responsibility of assessing the safety of the product and properly informing consumers.

In many cases of safety and risk, the intentions of society become codified in laws and oversight agencies. We have codes that contractors must follow in order to produce buildings that are structurally sound and provide minimum protections in the case of fire. We have codes that define how safe automobiles must be constructed. We have agencies that oversee the operation and maintenance of airlines. The advantage of legal protections and oversight is that we don't need to assess the safety of a building, car, or airplane every time we use one. The disadvantage is that we can become lulled into thinking that the government is always looking out for our interests. Governments do not have the resources to police all technologies, and businesses do not always follow safety codes. In some countries, consumer protection laws create legal and market incentives to follow safety guidelines. These laws give consumers recourse to the courts, and in so doing make unethical behavior costly. Within such legal environments, companies that do not follow high safety standards or consistently violate codes incur high insurance costs (indeed, insurance company policies often become strong market based incentives for maintaining safety).

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14 Organization and Assessment

Regardless of whether people act ethically there is still the possibility that human error will occur. In fact, we can assume that since humans are not perfect, errors of judgement *will* occur in design and operation. We call such cases "honest errors" since they are not the result of negligence or unethical behavior. One obvious upshot of this is that we cannot design technologies assuming that humans will perform flawlessly. Technologies need to take human imperfection into account. In the end, it does not really matter whether a technological failure is the result of an honest mistake or ethical lapse – since the outcome is the same: injury and/or death. So we are faced with the task of figuring out how to prevent poor decision-making. Like ethical decision-making, simply asking people to not err cannot solve the problem. We need to address the structure of the decision.

One possible solution is to change the technology such that the number of critical decisions is reduced. One way is to choose technologies that are simple to understand, simple to operate, and simple to maintain. Another option is to choose technologies that are inherently safer. For example, a coal-fired power plant is inherently safer than a nuclear power plant. Though obviously the coal-fired plant produces significant quantities of pollution, a coal plant that malfunctions may explode and, at most, kill scores of people. A nuclear power plant that malfunctions can lead to tens of thousands of deaths as well as long-term radioactivity.

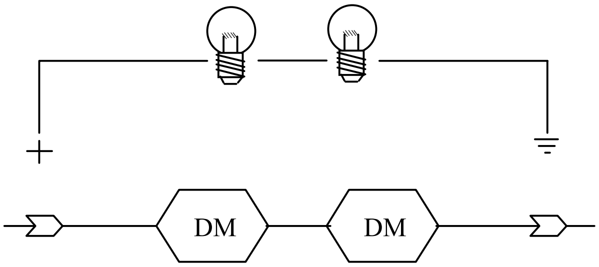
A third option is to simplify the operation of complex technology. For example, in Airbus aircraft, pilots don't actually "fly" the aircraft – a computer does. The pilots tell the computer where they want to go (through their inputs to a joystick and pedals), and the computer decides how best to position the control surfaces (ailerons, rudder, and elevators). The computer makes it impossible for the pilot to fly outside of the aircraft's operating envelope (limits of speed, altitude, bank angle, angle of attack, g-forces, etc.). Of course there is a cost to this: it adds complexity in the design of the cockpit – which may itself introduce new opportunities for errors.

But none of the technical solutions appropriately deal with the design stage. In fact, we seem to have only addressed errors made in the operational stage. To go further we need to consider changes to the decision making process – that is, the organization that surrounds and defines the way we make decisions.

For the sake of simplicity, let's imagine a single decision-maker (DM) who is given a task. What is to prevent the DM from making an error? We could train the DM with the latest techniques. We could provide strong incentives to encourage the DM to perform well (punishments and rewards). We could also provide the latest and most capable tools and equipment. But still, our DM is human, and despite our best efforts, s/he occasionally errs. What should we do to prevent this?

We can draw inspiration from machines and how they operate. Over time, all machines have parts that eventually fail. In machines where continuous operation is important (such as aircraft), the failure of critical components would probably result in significant injury and usually death. The responsible engineer not only designs parts to be strong, but incorporates redundant (or back-up) systems. Should the primary system fail, a backup takes its place and continues in operation. Can we apply the same idea to human organizations? Certainly.

Figure 14.1
Serial Systems

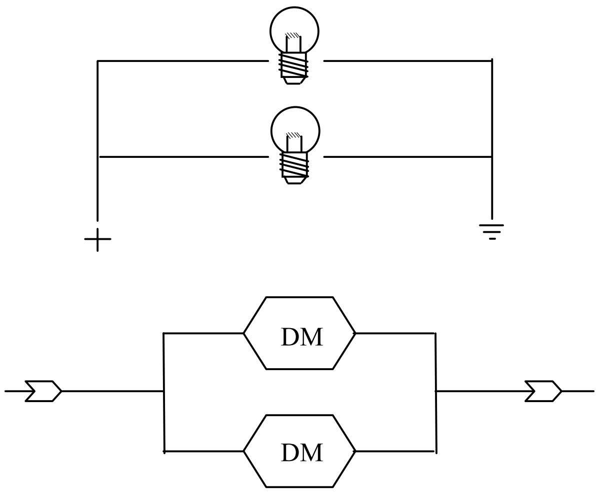


The system we have already described in which there is a single decision making unit is called *serial*. If you are already familiar with serial electrical circuits, the idea is similar. In a serial circuit, if one component fails, such as a light bulb, the whole system fails. Similarly, our DM is situated within a serial organization (where there may be other DMs working on different parts of the process. If s/he fails or errs in his/her job, the system fails.

You might already be imagining how we can modify our serial organization in order to decrease errors (and thus increase reliability). In an electrical circuit, we can create greater reliability by placing components in *parallel*. The failure of one light bulb does not stop the circuit (flow of electricity) – the second light bulb continues to shine. Similarly, we can design a *parallel* organization. A job or decision is given to two or more

DMs. Each DM (like the light bulbs in the parallel circuit) is independent. While one DM is, in theory, no more perfect than the other, the *chance* that both will fail/err at the same time or on the same job is *reduced* (but not eliminated).

Figure 14.2
Parallel Systems

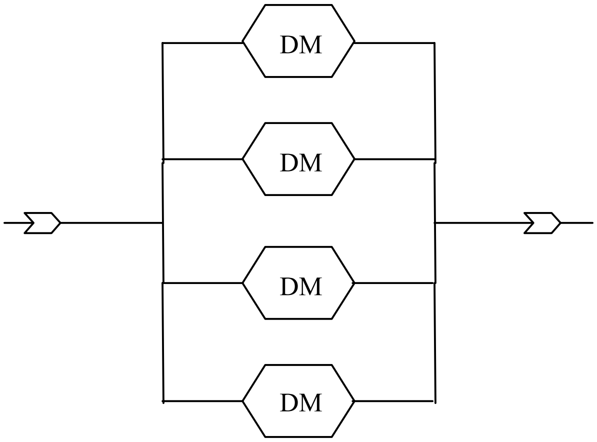


Adding additional DMs further reduces the chance of mistakes. We also have the option of placing certain restrictions on a parallel system. We could require that a majority of DMs agree. We could require that 75% of them agree (or any proportion we see fit). It all depends on the situation.

If we require that *all* independent DMs agree, than we a special variant: the *serial independent* system. This is actually a parallel system (because it has multiple DMs performing the same task), but it *acts* like a serial system in that if there is a single failure (or disagreement), the system stops. The advantage of a serial independent system over a purely serial system is an increase in reliability.

The system of decision making that we choose depends on our situation. We may think of two different circumstances. In the first, our priority is the completion of a project, process, or event. In such a case, a parallel system with at least one positive result will suffice. *The bias of the system is to continue despite failure/disagreement.* If, on the other hand, we require that no mistakes be made, we require that all DMs agree (serial independent). *The bias of the system is to fail/stop at the first sign of* *trouble*. We can see these different variations in action in the world around us. For example, the approval of pharmaceuticals (medical drugs) is often done with a serial independent system. There are multiple clinical trials, and if any of them fail, the approval process is halted until the reason for failure is understood and corrected.

Figure 14.3
Parallel System with Increased Reliability



Of course, in many situations the use of a parallel system can increase costs. A business would obviously be reluctant to use parallel decision making (or task processing) for all tasks, since this might multiply costs by the number of additional DMs. But in some critical decisions, where failure means loss of life or injury, the cost may be justified. Certainly we make similar decisions in regard to our own medical problems. For serious ailments, we may seek out the advice of more than one doctor – since we want a highly reliable assessment and solution. But cost does not have to always be an obstacle – sometimes creative reorganization of existing resources is sufficient to increase reliability. For example, with commercial passenger jets that have only two jet engines, the *same* mechanic is usually not allowed to carry out repairs on *both* engines. If s/he does something improperly, there is a chance that the error will be repeated in both engines. Instead, a different mechanic is used for the second engine. The chance that both will err simultaneously is less likely, and the chance that they make the same error is even smaller. The result is that the aircraft is more likely to stay in the air – since a loss of both engines would lead to certain catastrophe. The airline, for its own part, does not incur extra cost since they most likely have at least two mechanics anyway.

Another problem with parallel systems is speed. When only one person needs to decide, the process can be quick. When many people are part of the process, it can often be slower (unless you require only one person to advance the process – in which case parallel systems will, on average, be faster than serial). Thus, hierarchical decision-making processes, as we saw in the chapter on politics, tend to be quick. But we now learn they are less reliable because they are serial. More democratic processes are slower, but have less chance of making catastrophic choices (they are still possible, just less likely). The choice of which system to use will depend on our need for reliability, our available resources, and time.

Interestingly, in an area that requires quick decision-making, we are seeing a subtle movement away from strict hierarchy. Many pilot crews are now trained in a team approach to crew management. Tasks are shared – jointly understood and often jointly agreed upon. The captain is still in charge, but the operation as a team increases shared information (and thus awareness of problems) and decreases errors of judgement.

Parallel systems are not without their dangers – for both machines and organizations. Parallel systems can mask errors or failures in a system. That is, if there is a failure, and a backup system takes over, we may not know that there was a failure in the primary system. Were the system serial, we would identify the problem immediately. But with the parallel system, we may continue in operation *thinking* that we have back-ups, when in fact we are already using a secondary system. Clearly, this kind of masked failure is more likely in a machine, since human organizations are more likely to self-report failures.

Another danger is common mode failure. This occurs when systems or DMs that are supposed to act independently *do not* because they rely on some common input that is in error or broken. This could be true for both machines and organizations. We could imagine two independent mechanical systems failing due to a common failed power supply. Independent DMs could fail due to incorrect common information, training, or instruments.

Human organizations suffer a special kind of problem that machines don't. Because humans are aware of their social surroundings, they may not act independently. We can imagine a group of workers who have arrived at independent decisions, but in the context of meeting with their boss, they change their decisions based on what the boss or other workers say. In any group of people there are often leaders and followers, cue givers and cue takers. This erodes independent decision making and the reliability of the system.

Certainly, parallel systems are not a quick and easy solution to all technological failures. Indeed, in some cases, parallel systems do little to prevent catastrophe. With machines and large human organizations, complexity makes it difficult to predict how small failures will change the system – thus making it very difficult to build-in reliability. Which systems need to be parallel? In addition, where we have *tightly-coupled* systems, there is little room for any kind of failure. The shock of a single failure ripples through the entire system, setting off additional failures and often cascading into a growing number of uncontrollable failures. A simple illustration of this is a daily schedule that is very tight (absolutely no time between events). If just one event runs longer than expected, than the whole schedule is thrown off. This can be prevented with loose coupling (adding some buffer time between activities).

Before moving on, I wish to make one observation. Recalling the chapter on the history of science, we can think of western science as a kind of parallel system. Indeed, what western science does is produce *reliable* knowledge, more reliable than many other knowledge producing activities. Since the Scientific Revolution, competition and cooperation have been characteristics of western science. A new bit of knowledge discovered by one scientist will be reproduced by competing scientists. If they are not able to reproduce the results, then the new knowledge is considered in error. Establishing reliable knowledge depends, of course, on the exchange of ideas and methods in the first place (cooperation).

Technology Assessment

Aside from changing the organization, in order to prevent failure we can apply systematic decision making routines that help us predict technological outcomes (technology assessment, or TA). These processes were initially developed in the 1960s and 1970s at a time when many technologies seemed to be out of control. They were producing more problems in the long term than they were intended to originally solve.

Technology assessment is performed in a variety of ways, but in general, it always attempts to objectively anticipate the future impacts of technology. The focal point of the TA process can be projects, problems, or technologies (table 14.1). Generally, TA is used to find wide-reaching impacts from technology, and to examine the interaction of a technology within society and the environment (the latter usually being called "environmental impact reports or assessments", EIRs or EIAs).

Table 14.1

Type of TA	Example
Project	A specific sewage treatment plant
Problem	Air pollution
Technology	Nuclear energy (in general)

At its core, the TA process is quite simple. The first step is to establish what we know about the present. The second step is to create trajectories for society, the environment, and technology. The third step is to attempt to anticipate how these trajectories will interact, in both positive and negative ways. A slightly more detailed sampling of this process is given in table 14.2.

Table 14.2
Overview of Technology Assessment Process (from Shrader-Frechette)

1. Problem definition
2. Technology description
3. Technology forecast
4. Social description
5. Social forecast
6. Impact identification
7. Impact analysis
8. Impact evaluation
9. Policy analysis
10. Communication of results

Critical to nearly every TA is the identification of stakeholders, those persons and groups that have a special interest in the project, problem, or technology under discussion. Not everyone has an equal interest in all issues. Some persons and groups will be dramatically impacted. Stakeholders are usually essential to the success of a project, if for no other reason than they can help identify potential future problems or benefits.

TA can involve a number of different methodologies. Two common quantitative measures are cost-benefit analysis (CBA) and risk-cost-benefit analysis (RCBA). As the name implies, CBA compares costs versus benefits, usually with economic measures. RCBA adds an additional measure – the likelihood of something happening multiplied by the potential benefit or cost. CBA and RCBA are far from perfect. Many things that are essential and of value to us are also difficult to quantify. How, for example, does one accurately measure the benefit of a natural vista? Furthermore, costs and benefits, as well as their associated risks, may accrue to different groups of people. It is not as though we all share the same social, technological, and environmental balance sheet. Finally, because CBA and RCBA are quantitative, we can be fooled into thinking these are more authoritative than qualitative means.

The qualitative methodologies include a wide range of activities. There is information collection – such a simple library research. TA can also be done through questionnaires to experts or stakeholders. There can be public inquiries, or panels and testimonies. TA can also be done through social experiments, in which a technology is incrementally integrated and continually observed.

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15 Governance

In the previous two chapters we moved from issues of personal decision making to organizational decision making. Now we take this one step further and consider how technology is governed in general. Technological decisions, whether they are made by individuals or organizations (including government agencies), exist within social, political, and legal frameworks. These frameworks determine what are permissible technological decisions (e.g. is it okay to dump high levels of cyanide into a city's water supply) and how such decisions are made in the first place (e.g. who gets to participate in deciding safe levels of cyanide).

As in the previous chapters, there are a wide variety of approaches to governance around the world. No single approach is the best. Rather, we want to be familiar with the options available to us, and make responsible choices based on the values our community holds dear. Inevitably the technological decisions we make are not between right and wrong (ignoring for the moment those people who are negligent and/or wilfully ignorant of their actions), but are composed of many tradeoffs and unknowns. There are no simple answers. Our actions have real and long-term social and environmental consequences. What decision-making framework provides us with the set of outcomes that is in closest agreement with our values?

The astute reader may see similarities between the idea of technological governance and the previous discussion on technology policy (chapter six). There is significant overlap in the fact that both deal with government influence over technological directions. But there are also fundamental differences. In chapter six we were primarily concerned with how policies could be used in encourage technological development for economic growth. Here we are concerned with how those, *and other* decisions are made. Our interest is not strictly in economic growth, but in finding an agreement between technological change and our social values. This is a much broader undertaking.

How does society direct technology?

How have we come to build the world around us? What was the process by which we decided to design and make the technologies that we have? For the most part we can think of three different areas to study broad technological change: the government, business, and the market.

By now you should have a strong appreciation of the way in which governments influence technology (chapter seven). We examined a number of different policy mechanisms, such as intellectual property rights, safety standards, and R&D funding. *Who* makes these decisions? Voters? Legislators? Civil servants? Lobbyists? Interest groups? Voters are at a distinct disadvantage because they do not have access to all decisions. They usually participate in the political process only one or two times a year, casting ballots for representatives. We would hope that legislators would be responsive to their public, but they also respond to powerful business lobbies and high-profile interest groups. And just like voters, legislators are not present for all technological decisions. Civil servants, who must interpret the broad outlines of legislative bills, make many of the day-to-day decisions.

Businesses play an important role in the development and use of technology. This book has identified firms as a crucial element in the development of innovations. Who are the people that have a say in such business decisions? Laborers? Engineers? Managers? CEOs? Shareholders? Workers within a company, as we have seen, have limited scope for influencing decisions. They are typically expected to leave their personal philosophies at home, and assume the corporation's interests at work. Profits, not social policy, are the priority of the day. Decisions are made within an opaque (not visible to the public) hierarchical structure. Most businesses themselves have limited scope for influencing broad technological change, but they do act in concerted fashion through industry associations. In many cases, however, these associations mirror the underlying profit motives rather than larger social interests.

And then there is the market, the place where most of us have our greatest impact on the future. Our days are made up of many small decisions, as consumers, which collectively push the market one way or another. We choose whether to drive a car, take a bus, or ride a bicycle. We decide whether to turn on or off a light, to use an air conditioner, to take a long or short shower. We buy things to eat, to wear, and to furnish our homes. And our leisure activities are often largely dominated by consumption of products and services. In consumption we have a wide variety of choices available to us, yet our day-to-day consumption is typically not in agreement with most of our visions of the future. Why? We tend to view our own personal decisions as insignificant. We understand that unless most people act in concert, our individual decision will have a negligible impact. And most of the time we are too worried about our short term problems (e.g. "what will be on the final exam?!) and tell ourselves that we'll worry about the long term problems (e.g. global warming) later.

Is there a plan?

What should be obvious from looking at these different groups is that there is no clear plan on what our technological trajectory ought to be. Disparate groups make decisions on a piecemeal (bit by bit) basis. There is no overarching understanding of how all the small pieces fit together. There is little emphasis on matching short-term goals (get re-elected, make money, get through the day) with long-term social and environmental goals. The technological world we have is, as Langdon Winner notes, more by accident than design.

The lack of a plan is a byproduct of there not being any single venue or location for a public dialog about technological decisions. Indeed, it is not merely a matter of not showing up to register one's vote (as an actual voter or even as a consumer). Many decisions simply don't take place in the public arena. Decisions made by the corporate world are, for the most part, done behind closed doors. Even workers within a company, as noted above, have little say over what goes on outside their immediate area. Making this worse is the fact that beyond a very narrow range of issues (health and safety, economic stimulus, town planning, military, and some R&D), it has not been the traditional role of government to weigh in on technological matters. These activities have been ceded to the commercial sector. Even when the government does involve itself, programs do not form an integrated technology strategy, and the public often does not have good access to the process. It is usually the case that the public learns about the government's plans after they have been drafted. Such public hearings are, in truth, more about selling the proposal than gathering public input.

Why a public sphere?

The necessity of bringing technological decisions into a more public sphere comes from a number of reasons. First, there is mounting evidence that the current technological system, which operates largely within a market-based framework, is not sustainable. The significant damage being done to the environment, including resource depletion, will, in all likelihood, lead to significant economic repercussions. These problems will appear in the next thirty to fifty years (though probably not before the current slate of government and business leaders have passed away). Second, there are already environmental, economic, and cultural changes underway that many people find unconscionable. Should these changes be the result of an "accidental" technology plan?

The third and most important reason for involving the public is that these decisions are not solely the province of experts. We don't have the option of leaving important questions up to a technical elite. Scientists and engineers do not have a single answer to all questions. They are not necessarily expert in evaluating how technology operates in a social context. And they do not necessarily reflect the values held by the public. When we are confronted with a technological decision, it is normally not a question of good and bad, but of trade-offs. We have to make compromises, a typical one being between short-term economic gain and long-term ecological sustainability. A technical expert is not qualified to make this decision for the general public. He or she *can* inform the public and help it come to its own conclusions. Ultimately this depends on our social values.

Solutions?

We can't expect governments, businesses, or consumers to change overnight. As it becomes increasingly clear to more and more people that the very engines of our economic success threaten our future, we will see growing calls to do something. It is likely that until we witness catastrophic failures in ecological and economic systems, change will be slow and incremental. Below are three areas where people can begin to bring technology under control.

To begin with, there is the simple problem of information and education. We need transparency in both the nature of technology, as well as the decision making process. When we buy and use technologies, we ought to know more than the glitzy marketing campaigns tell us. When we purchase food, for example, it should be accompanied by truthful and useful nutritional information. This is similar to what we learned about risk and safety: that something is safe when the risks are known and judged acceptable. But this concept has traditionally been applied only to life-threatening situations. What if we extended the concept to technology in general? Wouldn't we all be better off making educated decisions about what we consume (and I'm not talking just about food). As for the decision making process, when this is made transparent to the public, we better understand the tradeoffs that have been made. Governments and businesses often don't want the public to witness their meetings because they know that some decisions are not in agreement with the general public. Exposing the decision-making process goes a long way to ensuring better public accountability. It is not surprising that in areas where the press has a high degree of freedom, we see greater public accountability in technological projects.

Another important step is increased possibilities for participation in technological governance. This is already being done through interest and lobby groups. Within democracies, interest groups are among the most powerful means for pushing technological debates into the public arena. As individuals we do not have enough power to demand access to the process, but as groups, we are better able to influence governments and businesses. Groups can form consumer solidarity, and through public relations campaigns make people aware of the consequences of day-to-day activities. A good example of this was the dolphin-safe tuna campaign in which consumers, through a boycott, forced most canned tuna producers to alter their fishing practices. When consumers speak up and express their interests, businesses listen.

A third area is in learning how to connect our individual decisions with larger technological trends. We don't need to act as though we are powerless, that the technology controls us. In fact, with what you have learned in the previous chapters, you are (supposed to be) empowered to make responsible technological decisions – responsible to your individual beliefs, to your local and global communities. The changes you make in your personal life may have a negligible effect on the overall technological trajectory, but it is the beginning of a path towards mastery of the future. It better prepares us for steps we will have to take, and serves as an example to those around us. There is little point waiting for others to fix the system if we find ourselves unwilling to do so.

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